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Our Solar System and the Stellar Universe

Ten Popular Lectures

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Astron
W

OUR SOLAR SYSTEM
AND THE
STELLAR UNIVERSE
Ten Popular Lectures

By
Rev. CHARLES WHYTE, LL.D., F.R.A.S., F.R.S.E.
Kingswells, Aberdeen

WITH FRONTISPIECE, 18 PLATES, AND OTHER ILLUSTRATIONS

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PREFACE

One of the earliest emotions that can have touched the heart of primitive man, must have been a sense of wonder as he lifted his eyes to the starry heavens above him. That wonder has only deepened with the passage of untold centuries ; and, since the first, faint dawn of scientific awakening, the study of the marvels of astronomy has been a subject of absorbing interest, the fascination of which has appealed to the whole circle of the human race.

The profoundest depths of man's nature have been moved by the glory and beauty of the stellar universe, and, while science has been sometimes accused of tearing the veil from the sanctities of the Divine Creation, here, at least, revelation has only added to the feeling of reverence and awe with which our forefathers gazed on the splendours of worlds other than their own. Science is, after all, but the handmaid of religion, and nowhere has she, within recent years, paid higher tribute to the majesty of the Divine creative power than in the realm of astronomy.

The main purpose of the present volume is to indicate some of the more recent discoveries of science in relation to stellar phenomena, and to express them in language that the lay mind may be able to understand their significance. Modern astronomical facts and theories are to be found for the most part in technical books, which are neither readily accessible to the ordinary reader, nor sufficiently intelligible to many who desire to know something of the wonders of the universe around them. The writer believes there is room to-day for a popular book on astronomy which may reveal in some fashion, however inadequate,

the enormous advances that have been made in recent years in this department of knowledge.

The present volume does not profess to be a treatise on astronomy, nor does it attempt to cover the whole field of modern research. The writer will be content if he has been able to present, in popular form, the salient facts on the various topics with which he deals. These can never fail to be of interest to the human mind, and, as they are but symbols whereby the human spirit can rise to a truer knowledge of the God Whose wisdom and power they reveal, their moral value must not only be acknowledged as among the most potent in the sphere of nature, but of the profoundest interest to every seeker after the truth.

This aspect of the subject I have endeavoured to keep constantly before me. Science cannot be divorced from religion, although in its own particular province it is generally regarded as independent of moral issues. Astronomy presents one of the best fields for a correlation of the two realms, that is not only desirable, but necessary.

Among the numerous sources from which information and help have been drawn in the preparation of these lectures, I acknowledge my especial indebtedness to the "Adolfo Stahl lectures in Astronomy." "Binary Stars," by Professor Aitken. "Introduction to the study of Variable Stars," by Dr. Caroline Furness; Journals of the British Astronomical Association, Monthly Notices of the Royal Astronomical Society, and Popular Astronomy.

Acknowledgment must also be made of most valuable assistance and suggestions rendered by the Rev. John Thomson, M.A., Hons., United Free Church Manse, Carmyllie, Arbroath, and the Rev. A. L. Cortie, F.R.A.S., F. Inst, P., Director of Stonyhurst College Observatory, Blackburn, Lancashire, to A. C. D. Crommelin, B.A., D.Sc., F.R.A.S., Royal Observatory, Greenwich, Past President of British Astronomical Association and Director of Cometary Section, and the Rev. Martin Davidson,

B.A. M.Sc., F.R.A.S., Director of the Meteoric Section of the B.A.A. for their useful suggestions and friendly criticism; to Charles L. Brook, M.A., F.R.A.S., F.R. Met. S., Director of the Variable Star Section of the B.A.A. for reading lectures VII. and VIII. respectively, and to Walter Goodacre, F.R.A.S., Director of the Lunar Section and President of the B.A.A., for reading the second lecture. To all these gentlemen I desire to express my sincere gratitude for their kindness.

I am greatly indebted to Dr. Caroline Furness, Director of Vassar College Observatory, and Messrs. Houghton Mifflin, Co., Publishers of "Introduction to the Study of Variable Stars" for permission to reproduce the illustrations of the Solar Spectrum and several light curves.

I also wish to record my obligations to the following distinguished astronomers who have most generously placed at my disposal the beautiful photographs which, in themselves, would add distinction to a far more ambitious volume than the present:—Professor E. B. Frost, Director of the Yerkes Observatory, Professor Aitken, Lick Observatory, Professor Bailey, Harvard College Observatory, Professor Plaskett, Dominion Astrophysical Observatory, Victoria, B.C., Rev. A. L. Cortie, Stonyhurst College Observatory, Major W. J. S. Lockyer, Ph.D. To these I offer my warmest thanks.

Last, but not least, I have to express my most cordial thanks to the Senatus of the United Free Church College, Aberdeen, for the honour they conferred on me in inviting me to deliver the Thomson Lectures for the session 1919-1920, which form the basis of the present volume.

CHARLES WHYTE.

United Free Church Manse,
Kingswells, Aberdeen.

Our Solar System and the Stellar Universe.

LECTURE I.

The Sun.

The Sun is our nearest star, and, like all the other stars, he shines by his own inherent light. Were he placed at the distance from us of Sirius, the brightest star in the heavens, his luminosity would be reduced to a star of the 2nd magnitude. Thousands of stars are greater in bulk and light-giving power than our Sun is. It is only because he is so immensely nearer to us, compared with other stars, that he is such a powerful body. To us he is the most important of all the stars, not only because he is by far the most conspicuous luminary in the sky, but also because he keeps our Earth and the other planets in their orbits by his attraction. All our light and heat are derived from him. As showing how much we are dependent upon him for heat, it has been calculated that, supposing the Sun were to be blotted out, in three days from its extinction there would be no life, animal or vegetable, on our planet, except perhaps among deep sea fishes. In two days all the vapour in the atmosphere would be thrown down in rain or piles of snow, and then a frost would succeed, greater than is felt in the Arctic regions.

The Sun is a most interesting body to investigate, owing to the fact that he is the only star close enough, comparatively speaking, to permit us to study it in detail.

The diameter of the Sun is 865,000 miles, or 109

times that of our Earth. His bulk or volume is 1,300,000 times greater than the Earth. In other words, it would require 1,300,000 globes as big as our world, rolled into one, to form a globe as large as the Sun. His mass is 332,800 times that of the Earth. It is this gigantic mass which gives the Sun his immense gravitational power, a power strong enough to maintain the planets in their elliptic orbits around him. The Sun at his surface has an attractive force of 27.6 times that at the Earth's surface, and a man weighing eleven stone on the Earth, would weigh at least two tons on the Sun, and would be crushed to death under his own weight.

Then again, the circumference of the Sun is $2\frac{3}{4}$ million miles. Suppose a railway train travelled at the rate of sixty miles an hour, it would take it about five years to go round the Sun.

The Sun is so far off that light takes more than eight minutes to reach the Earth. We only see the Sun as he was eight minutes ago, and yet light needs but one second to travel 186,330 miles. A train going a thousand miles a day would take 254 years to make the journey. Owing to the rate at which sound travels, viz., 743 miles an hour, an explosion on the Sun would be heard by us fourteen years after it actually occurred.

These facts give us some idea of the immense distance of our Sun.

A story is told of a Scotch shepherd. Two Englishmen found him resting on a hill, and considered him a suitable subject for some sport. "I say, Malcolm, you'll get a very fine view from this; you must see a long way off." "Oh ay, sirs," said Malcolm, "A very fine view. I can see a long way off." "You must see to America from here, I am sure." "Ay, farrer than that, sirs, farrer than that." "Indeed? Further than America? Where can you see to?" "Oh I can see to the Mune," was the reply. Well, the moon is 100 times further away than America, and the Sun is 400 times further away than the Moon, being upwards of 90,000,000 miles from the Earth. It is all very well to talk of this big number,

but it is really very hard to conceive what a million is. You would get the best idea of it by trying to count it, but there are very few who would like to undertake that task. If you are very quick you might manage to count 200 in a minute. Well, you must go on at that rate for 83 hours or for nearly four days and three nights without stopping one moment for meals and sleep, and then you would have counted a million. It takes the seconds hand of a clock more than $11\frac{1}{2}$ days to tick a million.

METHODS EMPLOYED FOR OBTAINING SUN'S DISTANCE.

Several methods have been employed for ascertaining the distance of the Sun from the Earth, five of which are worthy of special mention. The first is by the transits of Venus; the second is by means of the velocity of light; the third is by the aberration of light; the fourth is by observing the opposition of Mars; and the fifth is by observing the parallax of one of the Asteroids when in opposition.

It is somewhat difficult to ascertain the way in which the distance of any inaccessible point can be measured. Surveyors use an instrument by which they can tell the direction of any far-off object, such as a tree or a building as seen from each end of a line they have measured on the ground. They call that the base line. Knowing the direction and the length of the base line, they can get the distance of the tree or building by an arithmetical calculation dealing with the angles got by the base and the lines from its ends drawn to the object. By a nearly similar process, but on a far larger scale, the distance of the Sun and planets is determined. But in this case the base line has been as long as from Scotland to the Cape of Good Hope.

The method of ascertaining the Sun's parallax by means of a simultaneous observation of the transit of Venus from different parts of the Earth's surface, was recommended by Halley in 1716. He bequeathed the observation as a task to posterity. His suggestion has this advantage, that it substitutes an observation of the

time of a transit of Venus across the Sun's disc for instrumental measures of angles which are more or less difficult and always uncertain.

In order to determine the solar parallax by a transit of Venus, two Observatories are selected as far apart in latitude as possible. Then her apparent displacement on the Sun's disc, due to a change of the observer's station upon Earth, is the difference between her own parallax, due to this displacement and that of the Sun himself. Hence, the object of the observation is to obtain a value of the angular displacement of Venus on the Sun's disc, due to the known distance between the two observers' stations on Earth. The paths of Venus, as seen from the two stations, will be apparently two nearly parallel chords on the Sun's disc. The problem is, to find the length of the arc joining their two centres. The duration of the transit, or the time when Venus enters on the Sun's disc, and again when she passes off, must be noted at both places. When the durations of the transit at the two Observatories are known, along with the hourly motion of the planet, the length of the two distinct chords described by Venus upon the Sun, is found and expressed in seconds of arc. The Sun's parallax is then found by the difference of time observed at both stations. It has been noticed, however, that the planet, at the time of internal contact, has shown a ligament instead of a round disc touching the Sun's edge. When this happens, the time of actual contact is uncertain to the extent of about a quarter of a minute.

The way in which the Sun's distance can be determined by the velocity of light, is by means of the eclipses of Jupiter's satellites. Some time after their discovery, it was found that their eclipses occurred too early when the giant planet was at his nearest approach to the Earth, and too late when he was at his greatest distance. The difference between the early and the late eclipses was about 1000 seconds. Olaf Roemer, a Danish astronomer,—(the inventor of the transit instrument and meridian circle) was the first to attack

the problem, in the year 1675. He assumed that light requires a certain time to travel, and therefore occupies 1000 seconds in traversing the entire width of the Earth's orbit, or the difference between the nearest and the farthest distance of Jupiter and his satellites from us. Therefore, light requires eight minutes twenty seconds to travel from the Sun to the Earth, or one half the difference of distances. The Sun's distance can thus be obtained by multiplying the velocity of light, 186,330 miles per second by the time, approximately 500 seconds. This is equal to 93,165,000 miles. Taking this to be the value of the Sun's distance, the Sun's parallax is about 8.78 seconds.

The third method of obtaining the Sun's distance is from the aberration of light, discovered by Bradley in 1728. The aberration of light is the apparent displacement of stars due to the combination of the velocity of the Earth with that of light. The Earth's motion of $18\frac{1}{2}$ miles per second, produces a sensible deflection in the direction of the rays of light approaching us. Were we, for example, standing still in a vertical shower of rain, the drops would fall in perpendicular lines. Were we, however, to walk or run forward, the drops would strike our face. Were we to increase our speed, the deflection in the direction of the drops would become greater. So is it with the light of stars. In consequence of the velocity of the Earth in its orbit, stars are apparently displaced when the Earth is moving across the line of sight. For six months the displacement is in one direction, while in the next six months it is in the other. A star situated at the Pole of the Ecliptic is displaced by 20.47 seconds in a direction that makes an annual rotation, this quantity being called the "constant of aberration." The velocity of the Earth in its orbit, and the velocity of light, have a ratio which is the tangent of the angle of aberration, or the "constant of aberration." The mean velocity of the Earth in its orbit, is equal to the quotient of the circumference of the Earth's orbit and the length of the year. The circumference of the Earth's orbit involves a knowledge

of its radius. The velocity of light has also been very accurately determined by physical experiments. Hence, using this " constant of aberration " and the velocity of light, the Sun's distance is found to be 92,975,500 miles, and, with a value for the Earth's equatorial radius, 3963.296 miles, we obtain 8.79 seconds for the Sun's equatorial horizontal parallax.

The solar parallax can be obtained by observing the displacement of Mars among the stars when he is in opposition. By means of these observations the distance of Mars from the Earth can be found, and this is the difference of the distances of the Sun from the Earth and Mars respectively. By Kepler's third law, the ratio of their mean distances may be determined by comparing the sidereal period of Mars, 684.5 days, with the Earth's sidereal year. The method of finding the Sun's distance by observations at a single observatory of the parallax of Mars when in opposition, was employed by the late Sir David Gill at Ascension Island in 1877. He was sent out there for that purpose by the Royal Astronomical Society. In observing the opposition of Mars in that year, he employed for his measurements a heliometer which had been lent to him by Lord Lindsay of Dunecht, Skene, Aberdeenshire. He ascertained the displacement of Mars among the stars by taking 350 sets of measurements which he made by morning and evening observations. From these measurements, he obtained 8.78 seconds for the solar parallax.

The Sun's parallax may also be determined by observing the parallax of one of the asteroids when in opposition. The method is similar to that employed in the case of Mars. In 1877 Sir David Gill made observations on the parallax of Juno, Victoria, and Sappho, and found the value to be 8.8 seconds, a value now in universal use. This corresponds to a solar distance of 92,874,000.

The minor planet Eros, which is only about 20 miles in diameter and was discovered in 1898, is also employed for determining the solar parallax. Some

times its distance from the Earth is only 14,000,000 miles. In 1901 a series of photographs was obtained of its position among the stars, in the favourable opposition of that year, by no less than 58 Observatories. The way in which the Sun's distance was obtained by means of Eros was, by comparing photographs taken simultaneously at two different stations.

The asteroid shows a different position among the stars on the two photographic plates. It is by means of this shift that the distance is measured. Mr. Hinks' determination of the Sun's mean distance was in substantial agreement with that derived by Gill from observations of the asteroids. Eros' next close approach will take place in 1931.

THE TELESCOPE.

We cannot reach the Sun by the sea, nor by the land, nor by the air. How are we then to reach it? Well, in the words of an old proverb, "If the mountain will not come to Mahomet, Mahomet must go to the mountain." We have brought the Sun nearer to us by the use of the telescope, which is able to bring it within 100,000 miles of us.

By the aid of this instrument we may admire worlds that are inconceivably far away, as if they were brought many times nearer.

The invention of the telescope is sometimes ascribed to Galileo, an Italian, who made an instrument and first used it in 1610 A.D. and discovered four of Jupiter's moons by means of it; but the principle on which it was based was known before. In fact Galileo simply worked out the discoveries made by such opticians as Lippersheim of Middelburg and Janssen, another Dutchman who had been experimenting with lenses since 1590.

Janssen made some instruments of this kind that brought objects nearer. He made a present of one of them to the Prince Maurice of Holland, and was desired by the Prince to keep his discovery secret, as he thought he might get some advantage over his enemy

by one of these instruments, Holland being then at war with France.

But we may go much further back than this; for the early origin of the telescope, like that of most other important inventions, is lost in obscurity. Passing over the reputed discovery of magnifying lenses amid the ruins of Nineveh, and the fact that such were found in Pompeii, it may be interesting to mention, that Friar Bacon, more than 600 years ago, seems to have had some rude but correct ideas on this matter. He said lenses might be so figured that one object might be multiplied into many, and that those that were small, might be made to appear large; and further, that he could make stars appear whenever he liked. Now from these expressions, it is quite possible that this old philosopher may have made telescopes of small magnifying power, though they were for his own amusement, and never came into general use. He was a man of most extensive learning, and spent no less than £2000 in experiments on instruments and in procuring scarce books. We must not, however, deprive Galileo of the glory of bringing the telescope into use as it is at present. He had to encounter enormous opposition. His first discovery, as has been mentioned, were the moons of Jupiter. Many refused to look through his telescope. Others said there could not possibly be moons attached to Jupiter, for, to believe that, was to introduce more than seven bodies into the solar system, and there could not be more than the old seven planets since there were only seven openings in the human head! It may be interesting to note that the glass of Galileo's telescope is still preserved at Florence.

The reason why Galileo's telescope was not so popular at first, and one quite in keeping with the spirit of the times, was that it showed men some of their errors. At the invitation of the Senatus of Venice, he put his telescope on the tower of St. Mark's in that city, and showed them various sights that vindicated the truth of the system of Copernicus. At one time people imagined that our world was the centre of the universe,

and that the Sun, planets, and stars went round it. The ancient Greek philosopher Pythagoras and his disciples had taught differently from this, and Copernicus revived their theory, showing that the Earth goes round the Sun. The discoveries that resulted from the invention of the telescope, confirmed the truth of the system of Copernicus.

We know that the Sun was worshipped by the ancients as a god. Sun worship, indeed, has been the most universal of all the forms of idolatry. The Greeks used to speak of him as driving his chariot, to which four horses were yoked, across the heavens every day; and the story was current that the daughters of the god one day yoked the horses, and his son Phaethon, from whom we derive the word phaeton, took his father's place in the chariot and began to drive. But the horses, perceiving the weakness of the presumptuous young man, ran off, and approached so near to the Earth, that, if Jupiter had not taken both the horses and the young man in hand, our Earth would have been burned. The telescope, however, is much superior to Phaethon, for, while it brings the Sun as near as he did, it does not threaten to set our world on fire.

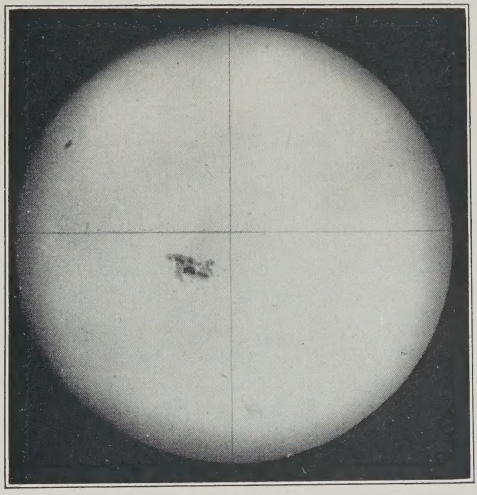
In all ages, men could not help observing with wonder the movements of the Sun. Where does he go in the evenings, and how can he appear next morning in an opposite part of the sky from which he disappeared the previous evening? Why are his movements so continuous and so uniform? All sorts of theories have been put forward by dark and unlettered minds to explain these movements of this great luminary. Mungo Park tells us, for example, of one African tribe, who believed that the people of the west fired the Sun when he got down to them; and, after heating him for another day's journey, took him round by a private passage to the east, to begin his "round" again. One philosopher in ancient times thought that the Sun was a fire kindled every morning and drowned out every night; and that eclipses were due to the want of coals, just as an engine would come to a stand-still for want

of steam. Another philosopher, dealing with the physical features of the Sun itself, thought that it might be no bigger than a man's foot; another that it might be as large as Greece; while another was considered insane, because he believed that all worlds were as flat as pancakes and supported by their surrounding atmospheres! Still, you must not imagine that all the ancients went as far astray, for Thales, one of the first of the Greek astronomers who had been educated in Egypt, taught that the Sun's light was due to fires, and that eclipses were caused by the Moon.

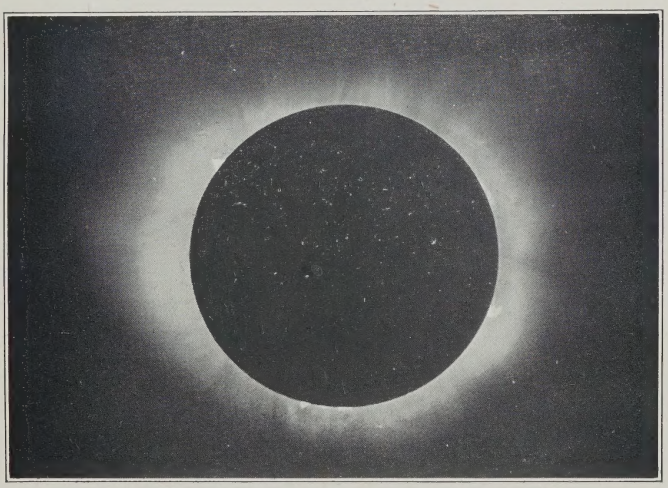
SUN-SPOTS.

One of the first old-world notions put to flight by the telescope, was that of the Sun's spotlessness. The natural purity of the Sun seems to have been an article of faith with the ancients, and one on no account to be called in question. So, when Scheiner, a Jesuit of the early part of the 17th century, reported to his superior that he had actually seen spots on the Sun, he was told it was all nonsense. "I have read," his critic said, "Aristotle's writings from end to end many times, and I can assure you that I have nowhere found anything in them similar to what you mention. So, go my son and tranquilize yourself. Be assured that what you take for spots on the Sun are the fault of the glasses, or your own eyes."

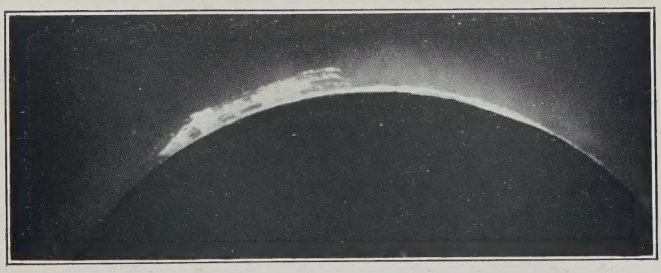
Galileo's new instrument, however, overturned this idea of the immaculateness of the solar sphere. Galileo began his telescopic work in 1610, and in less than two years after, he wrote a letter asserting that the spots which he had observed on the Sun's surface were real. Other astronomers corroborated his statement; but in spite of this, it remained almost unheeded for 150 years. Subsequent discoveries proved that these spots are found to be limited to certain zones. They get quite near the Equator before minimum. We modestly call them spots, and yet some are large enough to swallow up the Earth and half-a-dozen of our sister planets.



SUN. Showing large sun-spot. Feb. 3 1905. R. O. Greenwich.



SOLAR CORONA.



SOLAR ECLIPSE.

It might be worth while remarking in passing, that, to observe the Sun without any undue risk, we must put a piece of dark-coloured glass before the eye-piece of the telescope, as the Sun is far too bright to be looked at without this precaution. A very good method for observing the Sun is to fix a white paper on card-board to the telescope by a simple frame, 12 inches distant from the eye-piece. If the telescope be pointed to the Sun, and the focus correctly adjusted, an image is formed on the white paper which exhibits the chief features fairly well. A square piece of card-board fitted round the end of the object-glass tube, will help to screen the paper from direct sun-light.

The observation of these spots was soon followed by another discovery—that of the Sun's rotation on its axis. The spots were seen to move across the Sun's disc, and, since they all moved in one direction, it was supposed by Galileo that, in some way or other, they were connected with a motion of the Sun on its axis; and, just as straws show the rate and direction of a stream, so these spots determine for us the direction of the Sun's rotation. We thus find that the Sun moves on its axis, counter-clockwise, *i.e.*, from left to right, in about 25 days. The Earth revolves on its axis in one day, and the Moon in 27 days.

To come back to our study of the solar envelope, before considering the nature and cause of these spots, I would ask your attention to what is known as their cycle. The best illustration perhaps of a "cycle," is given us by our alternations of day and night, or our Seasons, which follow each other in regular succession at certain times of the year. That is their cycle—the order and times of their succession. Sun spots, it would appear, have also their cycle—a time when there are few, and a time when there are many—a time of intense activity, and a time of quiescence.

Schwabe, Wolf, and other astronomers who have studied the spots closely, and registered their observations, have discovered that the spottedness passes from minimum to maximum, and returns again to minimum

in a period of eleven years and a few weeks. During the minimum period, it is quite a common thing for spots to be wholly absent for several weeks. The maximum and minimum periods do not return with exact regularity. Sometimes the minimum period is a year or more behind its time, or ahead of it; and similarly for the maximum.

Some astronomers have tried to ascertain the cause of the sun-spot cycle, but their conclusions have not been proved to be very satisfactory. Others have supposed that the cause is to be found in the action of the planets. If there be any truth in this conjecture, the only planet that could, by any possibility, be the cause of this action, would be the giant planet Jupiter. It seems, however, that there is no inevitable connection, for the revolution period of that planet round the Sun is 11.9 years, whereas the sun-spot period is 11.1 years. Others have conjectured that the spots are formed when several of our planets are in the same straight line with the Sun. But, curiously enough, it so happens that there are as many spots to be noticed when the planets are equally and uniformly distributed round the Sun, as when several of them are in or near a straight line with the Sun. It is quite apparent that the cause of the sun-spot period lies within the Sun itself. There is every possibility of certain forces developing and accumulating within the Sun, until they attain such an intensity, as to break out once in every period of eleven years.

But you may ask—of what importance for the world is the knowledge of this cycle? I may mention, that it has been found, that the years when there have been many spots, have also been years of great magnetic storms and brilliant auroras, as if the solar activity was their cause. The solar influence on the magnetic elements cannot be doubted. It is both distinct and direct, and travels very rapidly, for a tremendous outburst of a spot on the surface of the Sun, has been often followed by a magnetic storm upon our Earth within a few hours.

One of these storms, Sir John Herschel speaks of as

something gigantic. Auroras were seen within 18 degrees of the Equator, where they hardly ever appear. These auroras were accompanied by unusually great electro-magnetic disturbances in every part of the world. In many places the telegraph wires refused to work. They had too many private messages of their own to convey! At Washington, America, the telegraph signalmen received severe electric shocks, and electric stations were known to have been set on fire. The fact of these disturbances is of no small importance to seamen whose steering depends so much upon the needle, which, in times of magnetic storms, is violently agitated.

But the knowledge of the sun-spot cycle is important in another direction. Some meteorologists have discovered that, when spots are numerous, cyclones are prevalent. The late Professor Charles Young, in his "General Astronomy," makes reference to the researches of Mr. Meldrum of Mauritius, who found a connection between the cyclones of the Indian Ocean and solar activities in the form of sun-spots. He also refers to the study of the meteorological records of the Argentine Republic made by Dr. Gould, showing an "indubitable connection between wind currents and the number of sun-spots." From all this it is apparent that, with sun-spots, there are connected magnetic storms, the aurora borealis and cyclones.

As to the nature of these spots—one astronomer in Galileo's time regarded them as planets or satellites moving round the Sun, like our Moon which moves round the Earth. Galileo himself, however, thought that if they were planets, or even mountains in the Sun, as another supposed, the one should hide the other as they approached the Sun's limb, which never happens. He therefore supposed them to be clouds in an invisible atmosphere of the Sun; upon which another remarks, that if this were the case, we should have a notched limb as the spots passed off the Sun's disc.

For one hundred and fifty years after Galileo's time, nothing was added to our knowledge of them, until

1769, when Dr. Wilson of Glasgow, after carefully observing a very large spot then visible, declared that a spot was a cavity in the photosphere, the bright surface of the Sun. It is undoubtedly the result of an eruption, or some other deep-seated cause which tends to produce rapid local, upward movements of a column of gas from the Sun's interior towards the surface of the photosphere.

In every spot there is a dark centre, called the "umbra." This is surrounded by a shaded area, called the "penumbra." There are brighter portions of the Sun, just as there are darker. As the darker are called "spots," or "maculae" in Latin, so the brighter are named "torches" or "faculæ." At times they cover immense areas of the Sun's surface. It is found that they are higher in the Sun's atmosphere than the spots. They are usually seen by contrast with the darkening at the limb, and also near spots. They are supposed to be caused by the uprush of gases from the Sun's interior to its higher atmosphere, and form the basis of the calcium flocculi.

It has been found that the gases in sun-spots are at much lower temperatures than those in the surrounding photosphere. It is a well-known fact that the sun-spot spectrum is different from the ordinary solar spectrum. Some of the lines are widened and strengthened, while others are weakened; some are doubled, while many fine lines, not present in the spectrum of the photosphere, are present in the spots. It has also been found that many fine lines in the spot spectra are caused by the formation of such compounds as magnesium, calcium hydride and titanium oxide, which can only exist at much lower temperatures than the photosphere. Father Cortie states that, as he has found water vapour lines in the sun-spot spectra, he believes steam must exist there.

SPECTRUM ANALYSIS.

For ages, ever since the eye of man saw the Sun, this question has often occurred to him—What is it made of?—and now at the present day we are able to say, we

know, to a considerable extent, of what materials it is composed. We are as certain as to some of these materials as we are in regard to those on our own mother Earth. The means by which this discovery has been made, is called "Spectrum Analysis." When a ray of sun-light passes through a prism of glass and falls upon an opposite screen, it is separated into the colours of a rainbow. These colours are produced by different rates of vibration of the various parts of the broken-up white ray. In music, if you take a tuning fork indicating the note C, and strike it against a piece of wood, it sounds, because it has set the air in motion, and its waves reach our ear so that we hear. Now this tuning fork C, causes as many as 256 such waves in a second, and we name the sound C. Suppose we sing upwards through the scale, and come to the C above; in doing so, we are simply increasing the number of waves per second, until, in high C, we are causing exactly twice the number that produced the original note, *i.e.*, 512. If we were going to the C above that again, we should have 2×512 or 1024 vibrations per second. You have this shown, to some extent, by the Aeolian Lyre, whose notes rise in pitch as the wind increases, causing more vibrations of the strings.

Now, just as the pitch of a musical note depends upon the number of waves of sound: (D for example has 288): so the colours of the rainbow depend upon the varying number of oscillations of the ether in the constituent parts of a beam of white light. Red rays have the longest wave length; while violet rays have the shortest. Indeed, there is almost the same proportion between the waves that produce the various rainbow colours, as we have between the waves that produce the notes of the musical scale. Of red waves at one end of the band, we receive about 390 billions per second; while of violet waves at the other end of the band, we receive about 770 billions per second. (We may say in passing, that heat is similar to light, only its waves have a slower motion).

To illustrate again by sound, the air is often in

vibration; but the vibrations are so few in number and so many, that they become inaudible to our ears. If, for example, the waves be fewer than 32 per second or more than 3000 per second, the sound is so low or so shrill that we cannot hear it ; and so, the waves caused by movements in the Sun, if fewer or more than a certain number per second, cannot be seen as light but may still be felt as heat in the former case, and detected by photographic action in the latter.

THE SPECTROSCOPE.

Now, to return to the analysis of our ray of light. When a beam of white light is refracted by a prism, it is at the same time dispersed, and emerges as a band of coloured rays, from deep red to extreme violet, which is called the spectrum. We have in nature, a spectrum formed from a curtain of rain drops, in the form of the rainbow; after refraction, reflection; then another refraction. The triangular glass pendants of chandeliers also give spectra of the white light viewed through them. When a beam of divergent or convergent light strikes a prism, the emergent rays are refracted at various angles. The consequence is, that overlapping of the rays takes place, and a mixture of colours is caused, so that the spectrum is lacking in purity, except at the extreme ends. To prevent overlapping of rays and images seen in coloured light, the white light must be admitted through a narrow aperture in the form of a slit, and the divergent pencil of white rays coming through the slit, must be rendered parallel by a convergent lens, which has the slit at its focus. This lens is called the collimating lens, and causes the beams of light to strike the face of the prism as a pencil of parallel rays. Consequently, in the spectrum so formed, there will be no confusion of images, and it will be a pure spectrum.

Incandescent solids, liquids, and gases under great pressure, give what is called a continuous spectrum; that is, a spectrum in which every coloured image of the slit is present, from the extreme red, through every

shade of red, orange, yellow, green, blue, indigo, to the limits of vision in the violet. Incandescent vapours and gases on the other hand, give only certain separate images of the slit, each gas and vapour having its own characteristic radiation. Thus, sodium gives a double yellow ray, lithium a red ray, thallium a green ray, iron and other metallic vapours a number of rays scattered throughout the whole spectrum.

A third type of spectrum is given when an incandescent vapour is superposed upon the background of a hot body, generally at a higher temperature, giving a continuous spectrum. In this case, the images of the slit given by the vapour, which are known as the lines of the spectrum, appear, by their absorption of the identical radiations contained in the luminous body giving the continuous spectrum, to be reversed, or to be dark instead of being bright. For instance, in a total eclipse of the Sun, if a spectroscope be directed to the crescent of the Sun still left uncovered by the Moon just before the total phase, a bright continuous spectrum will be seen, crossed by a very great number of dark lines. But the moment the Moon just covers the Sun, and so effectively removes the background giving the continuous spectrum, leaving the incandescent vapours isolated on the limb of the Sun, in a flash all the dark rays or lines are changed into bright lines. These dark and bright rays in the Sun and stars, have definite positions in the spectrum, corresponding to the oscillation frequency of the light waves which is causing them to appear. It is only necessary therefore, by laboratory experiments, to match the pattern and position of the dark rays seen in the Sun and stars by bright rays, to find out the constituent materials of the heavenly bodies.

FRAUNHOFER.

In the beginning of the 19th century, a German optician, named Fraunhofer, discovered, in addition to the beautiful band of colours, several dark lines (images of the slit) running perpendicular to the belt of colour,

and, strange to say, however often he got the colour band, he always found these lines in the same place. He measured their positions in the spectrum, and marked the more striking ones with the letters of the alphabet. Out of the large number he observed, he selected eight characteristic lines which appeared in the principal places of the spectrum. He marked these places by the letters A, B, C, D, E, F, G, H. In addition, he registered as many as 574 of these perpendicular lines, which are now called the "Fraunhofer lines." Since then, there have been added upwards of 20,000, and of these, more than 2000 are iron lines.

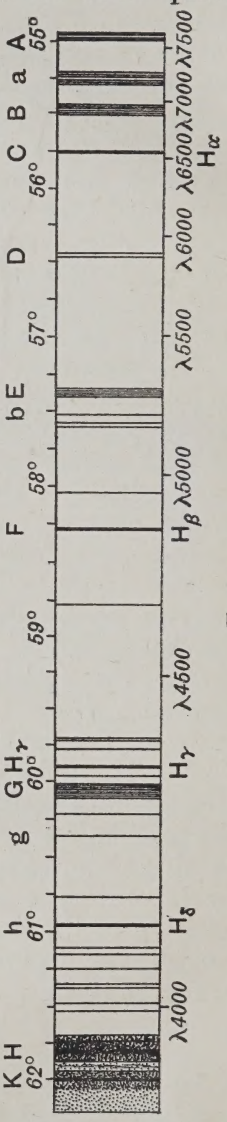


Figure 1

With the help of the diagram, I shall mention, briefly, the most important Fraunhofer lines, and their precise wave lengths. The length of light waves is not usually designated in fractions of an inch. The unit commonly used is the tenth metre, which is the ten-millionth part of a millimetre. In accordance with this system, the wave-lengths of lines in the visible spectrum, range from less than 4000 tenth metres in the extreme violet to 8000 in the extreme red. Consequently, lines will be represented by intermediate numbers.

To show that a number expresses a wave length, the symbol λ, which always represents wave length in optical formulæ, is written before it, as λ 7500.

The lines at A in the extreme red, are due to the absorptive action of oxygen in the Earth's atmo-

sphere. The wave length is 7594. The lines at small a are mostly atmospheric. The wave length is 7164. B lines in the deep red, are caused by the absorptive action of our atmosphere, and more particularly by oxygen. The wave length is 6870. C in the bright red, close to the orange, corresponds to H α, and is due to hydrogen. The wave length is 6563. The two close D lines in the yellow, are separated by six tenth metres, their wave lengths being 5890 and 5896. The one towards the red is called D_1; while the upper one is called D_2. They are due to the absorptive action of sodium vapour in the Sun's atmosphere. The lines in E, in the green, are due to iron. The wave length is 5270. In the bright green, we come to small b, a close group of lines, due to magnesium and iron. The strongest lines are designated by b_1, b_2, b_3, b_4. The wave lengths are, respectively, 5184, 5173, 5169, 5167 tenth metres. The first two and last lines are due to magnesium; while b_3 consists of two very close iron lines. F, corresponding to H β, is a strong hydrogen line between the green and the blue. Its wave length is 4861. The lines in G in the blue, are due to iron; and near it is H γ, the third line of the hydrogen series. The wave length of G is 4308, while that of H γ is 4341. Small g in the violet, is due to calcium, and the wave length is 4227. Small h in the violet, corresponds to H δ, and is due to hydrogen. The wave length is 4102, H and K in the extreme violet end of the spectrum, are two broad lines, due to calcium in the Sun's atmosphere. The wave lengths are 3969 and 3934. All these lines take us through the entire range of the visible solar spectrum.

There are at least 38 elements identified with certainty in the Sun. There are included in that number, the common metals of sodium, iron, calcium, magnesium, nickel, hydrogen, barium, copper, and zinc, all similar to what is contained in our own Earth. An American scientist of this century, Henry A. Rowland, has said that, if the Earth were heated until its temperature equalled that of the Sun, the Earth's

spectrum would probably resemble closely the spectrum of the Sun.

As to the presence of the heavy metals, such as gold, platinum, iridium, there is no definite proof. If they are present in the Solar Spectrum, the lines must be very faint. The classes of non-metallic elements, such as chlorine, bromine, oxygen, sulphur, and phosphorus, are not shown in the Solar Spectrum, except perhaps oxygen. The absence of lines, however, does not prove the absence of the element from the Sun. Probably the reason why the lines of some of the elements do not show in the spectrum is because they give relatively weak spectra, which are overpowered by the stronger spectra of those whose lines are visible.

The spectroscope has been of immense service in other ways. By its use we can find whether the Sun is approaching us or receding from us, and the velocity of rotation on his axis. This method of observation is known by the name of Doppler's method, introduced by Christian Doppler at Prague in 1842, and was at first applied to sound. Suppose you are standing on a railway platform as an express train approaches and passes you at full speed. The whistle is blown, let us suppose, before it comes near the station, continues blowing as it passes, and for some short time after it has passed. To the engine-driver, the pitch of the whistle is the same all along, but to you it is higher, and it remains sensibly constant till the engine is about to pass you, when it drops. A higher pitch shows more vibrations, and a lower pitch fewer vibrations; therefore, we conclude that the number of vibrations per second, caused by the whistle, is greater as the train approaches. Consequently, an increase in the number of vibrations is produced by the approach of the sounding body causing them, and a decrease by the departure of that body. As an engine whistle is higher in pitch when it is coming towards us than when it is departing from us, so, when light approaches very rapidly, it is blue, but when it recedes it is red. This is seen in the spectrum by a slight displacement of the lines towards

the violet or towards the red, according as the body is approaching or receding. By this method, the rotation of the Sun is proved by observations of his east and west limbs, for it has been found that the eastern edge of the Sun is approaching us, while the western edge is receding from us with a velocity of about 4,500 miles per hour. From this, it has been computed, that the Sun's equatorial region makes one complete rotation on its axis in $24\frac{1}{2}$ days. The Sun does not rotate as a solid body, for it has been found, that in the higher latitudes, the rotation is slower.

We can also ascertain, by the Doppler method, the velocities of currents of vapours and gases in the solar atmosphere around the sun-spots. It is found in the lower elevations of the Sun's atmosphere, that the flow from spots is out-ward along the Sun's surface, and consists of gases of heavy and rare elements; while it is inward for the higher lying gases, which are rushing into spots with very great velocity, and which are lighter and more abundant.

Another application of the Doppler principle has enabled us to measure the velocities of approach or recession of thousands of stars.

SPECTROHELIOGRAPH.

We cannot pass from the subject of spectroscopy, without mentioning that in recent years, a marvellous increase in our knowledge of the constitution and physical conditions of the Sun has been obtained by means of the spectroheliograph. The principle of this remarkable instrument was brought out by Drs. Hale and Deslandres, about 1890; but the first one of the kind was constructed and used in 1891. The spectroheliograph is an adaptation of the spectroscope, used in photographic observations of the Sun's disc, which practically renders it colour blind, except to some definite ray of the spectrum. The spectroscope, as we have already seen, will give a coloured spectrum of the Sun, crossed by a great number of dark lines. These dark lines, we may remind ourselves, are really

bright, but appear dark by absorption of light of the same wave-length contained in the continuous spectrum of the background. Let a second slit be placed just in front of the photographic plate, whose function is to exclude from the plate all the spectrum, except some definite selected ray. Let us select one of the two dark rays of calcium in the extreme violet. Now, allow the image of the Sun to pass at a suitable speed over the first or ordinary slit of the instrument. If the plate is kept stationary, it is obvious that the successive sections of the image of the Sun passing across the slit, will give a very over-exposed image of the ray isolated by the second slit. But, let the plate holder carrying the plate, in front of which is the second slit, be carried across the second slit by suitable mechanism at the same rate as the Sun's image is passing across the first slit. Obviously, as each section of the Sun's image passes by continuous steady motion in front of the first slit, the isolated calcium ray is impressing its image on the plate carried at the same rate across the second slit. The Sun is therefore made to paint its image in calcium light on the photographic plate, the plate being blind to every other ray. Now, it so happens, particularly in the faculae about sun-spots, that the calcium vapour is hotter than the calcium in the bright surface of the Sun. So the resulting image will be one of the bright calcium clouds above the solar surface scattered all over the Sun. The dark hydrogen absorption line in the red end of the spectrum, can be isolated in a similar manner, and the result will be a picture of the Sun as seen by the red hydrogen light, showing the bright prominences projected on the Sun's surface either as bright or as dark markings, according to their luminosity relatively to the bright solar background. These bright markings of calcium and hydrogen are called flocculi. Those of calcium are the upper portions of the solar faculae, and those of hydrogen are due to the solar prominences. By putting a disc in front of the Sun's image, on the first slit, it is also possible to photograph the bright prominences on the solar periphery in broad daylight.

either by the hydrogen or by the calcium radiations which they contain.

ECLIPSES.

But we must hasten on to mention other strange solar phenomena. You have all, I imagine, seen a partial eclipse of the Sun, and know that it is due to the Moon coming between us and the Sun so as to intercept its light. The last total eclipse in England, occurred in 1724. Sir J. Norman Lockyer says, "When the Sun is eclipsed, new glories in it are rendered visible. One seems in a new world, a world filled with awful sights and strange forebodings, and in which stillness and sadness reign supreme. The voice of man and the cries of animals are hushed, the clouds are full of threatenings, and put on unearthly hues. The very sea is irresponsive, and turns lurid red. All at once the Moon's shadow comes, sweeping over air and Earth and sky with frightful speed."

We know what impressions the eclipse makes upon the ignorant, whether at home or abroad. Columbus, you remember, profited by it in his dealings with the natives of America. Two great battles in ancient history were almost stopped by total eclipses of the Sun; and Lockyer tells us that, "during an eclipse in India, the natives gathered round himself and other astronomers, and almost prevented them from making any observation. Seeing in the eclipse their favourite god devoured by the monster, Rahoo, they rent the air with yells, moans, and hideous lamentations, as the monster seemed to get the upper hand. Their excitement increased, and they were just about to offer a sacrifice of fire by burning the long, dry grass that lay around. Had this been done, the smoke of the grass would have doubly eclipsed the Sun, and made observations impossible. But the flames were noticed and stamped out, and the smoke bank gradually died away; but the moans continued because Rahoo worked its wicked will."

But what is to be seen all this time? Lockyer again

says, "The astronomer at his telescope sees the edge of the Moon, which hangs like a black ball in the heavens, suddenly as if at the call of a magician, bedecked here and there with strange looking tongues of red fire. As the Moon travels over the Sun from west to east, these strange red flames, still maintaining their shapes, vary their sizes; and then, just before totality is over, another line of ridges is seen on the opposite part of the Moon to that on which they first appeared. Then the Sun appears again, and these strange things are lost to human eye, till another total eclipse comes round with its glorious revelations." Now, however, they can be seen by the spectroscope without waiting for an eclipse.

These red flames are called "prominences," and are often seen extending many thousands of miles beyond the limb, *i.e.*, the edge of the Sun. The late Professor Young of America saw one 100,000 miles long by 54,000 miles high, blown to shreds and thrown to a height of 200,000 miles at the rate of 162 miles per second. These prominences are found, not like the spots, which are confined to zones, but everywhere over the surface of the Sun—at the Poles as well as at the Equator. What are they? Up to 1842, they were considered to be in the Moon's atmosphere. In 1851, Sir George Airy, the Astronomer Royal, was convinced they belonged to the Sun; and in 1860 the question was set at rest by Delarue, who took a number of photographs of the Sun during an eclipse. He found that the prominences were eclipsed and uncovered, exactly as the Sun itself, and therefore must be part of the Sun.

But what were they composed of? Again the spectroscope came to our help. In the eclipse of 1868, the Spectrum of prominences gave bright lines; therefore, they were composed of incandescent gas; and, by October of the same year, Lockyer was able to say that the lines were those of incandescent hydrogen gas. Hydrogen gas was found in the atmosphere of the Sun in volumes beside which the size of the Earth is

as nothing, welling up in tongues of flame to a height of 70,000 and 80,000 miles, with speeds as high as 250 miles per second, sometimes running out into strange shapes and branches, at other times, parting from the lower surfaces, and floating cloud-like in the higher regions. These prominences can now be recorded on any clear day, by covering the Sun's image with a circular plate, thus producing an artificial eclipse, and taking photographs of them by the Spectroheliograph.

Prominences are the seats of movements, of which no terrestrial phenomenon can give us any idea, masses of matter many hundred times larger than the Earth, changing both place and form in the space of a few minutes. This hydrogen is found to surround the whole Sun as high as 5000 and 7000 miles. To this envelope of hydrogen is given the name of "Chromosphere," or coloursphere, *i.e.*, the Sun's upper atmosphere, because, to it is due the strange coloured appearance of the Sun in times of eclipse. Prominences, therefore, are nothing but portions of the Chromosphere blown up by ascending currents, local heapings-up of the hydrogen envelope which entirely surrounds the Sun.

Below the Chromosphere, is the Photosphere, the luminous surface of the Sun, the source of our light and heat. It forms the brilliant, visible disc of the Sun, and is the source of the continuous spectrum. Still, it is only a part of the Sun's atmosphere; so that the Photosphere and the Chromosphere, are the real atmosphere of the Sun. When the Photosphere is photographed, or observed with the telescope, the surface appears granular, with bright "mottlings" upon a dark background, called the rice grain structure. It is supposed that the bright patches, from 300 to 400 miles in diameter, are the tops of rising columns of hot vapours.

Regarding the constitution of the Photosphere, some scientists maintain, that it is a cloudy layer, like the clouds in our own atmosphere. They consider that it consists of the condensed vapours of a number of

different substances, among which iron, magnesium and sodium are especially prominent.

According to the investigations of Charles Abbot, Director of the Smithsonian Astrophysical Observatory, Washington, the temperature of the Photosphere cannot be less than 6,200 degrees Centigrade, and that of sun-spots 3,500 degrees Centigrade.

Moissau has discovered that all known elements vaporize at a temperature of 3,500 degrees Cent. or 6,300 degrees Fah. From these results, it is difficult to believe that there can be clouds in the Sun's atmosphere. The continuous spectrum must therefore originate in the lower and denser layers, under conditions in which gases show a continuous spectrum.

At the outer regions of the Chromosphere, is another envelope, called the " Corona " or crown, seen during the time of an eclipse of the Sun. This halo extends irregularly round the Sun, to a distance of 2,000,000 miles or more in the coronal streamers. What is the Corona composed of? It may partly be made up of minute particles surrounding the Sun, which are rendered luminous by certain radiations (perhaps of the nature of electrons) from the solar surface—especially the disturbed regions of sun-spots. There is also the distinctive element or substance, coronium, in the inner portions, showing a characteristic green ray that does not correspond with anything known either in the Sun or on the Earth.

MAINTENANCE OF SOLAR HEAT.

We come now to consider the maintenance of the Sun's heat. If it be due to combustion, where does the supply of fuel come from? If it were composed of coal supplied with oxygen, it would burn up very quickly if it continued to give out such a high temperature as it does at present. The amount of coal would soon be burned away, and the Sun's heat would disappear. It has been calculated that its combustion would supply the heat loss for only 5,500 years. Professor Campbell, Director of the Lick Observatory, says, " If one could

cover the Sun with a shell of ice 40 feet thick, the heat energy, radiated from the Sun at its present rate, would be sufficient to melt that shell of ice in one minute of time. To produce this quantity of energy from the combustion of coal, would require that a layer of the best anthracite 12 or 15 feet deep over the entire solar surface be consumed every hour. Now, if the Sun were composed of anthracite, the consumption of the whole mass would not furnish sufficient heat to supply the Sun's output at the present rate, for as long as 10,000 years." This is but a second of time in the life-history of the Sun. There must be some other agent, therefore, besides chemical combustion, to account for the facts.

Some have suggested that the Sun's heat is kept up by mechanical means. If the Sun were supplied with a constant stream of meteoric matter, poured into it with the great velocity of about 400 miles per second, that would no doubt produce a vast amount of heat. Still, it would not be sufficient to keep up the Sun's heat.

If each of the planets were to fall into the Sun from its present orbit, the present rate of radiation would be maintained for 45,604 years. This may be seen from the following table calculated by Lord Kelvin, in which the amount of heat is expressed in years and days.

Mercury	6 years	219 days.
Venus	83 „	326 „
Earth	95 „	19 „
Mars	12 „	259 „
Jupiter	32,254 „	
Saturn	9,652 „	
Uranus	1,610 „	
Neptune	1,890 „	
	45,604 years.	

The theory now generally accepted as being the chief cause in the maintenance of the Sun's heat, is that advanced by Helmholtz in 1853, viz. the Sun's shrink-

age under its own gravitational force, and the transformation of the work done by this shrinkage into heat. The estimates of energy available in the past æons from this source, are based upon the contraction of the Sun, from a diameter far beyond the orbit of Neptune, the furthest away planet of our solar system, to its present dimensions. The energy furnished by this shrinkage, would have kept up the present rate of radiation for nearly 25,000,000 years.

The late Sir Robert Ball, asserted a few years ago at the Royal Institution, London, that the Sun maintains its energy by consuming itself to the extent of nine inches of its diameter every day. If this estimate be correct, then the waste must amount to 1000 miles of the Sun's diameter in 20,000 years. Compared with the Sun's computed diameter of 860,000 miles, the diminution to 859,000 miles is so small, as not to be discernible. By a simple calculation, the Sun, at that rate, will last 17,200,000 years. The late Professor Newcomb computed, that the Sun will have contracted to one half its present diameter in 7,000,000 years, and cannot possibly supply heat adequate enough to sustain life for more than 15,000,000 years.

Though the contraction of the Sun upon its own material is probably the true source of energy, scientists are of the opinion that this, in itself, cannot wholly explain its great radiative power through the enormously long ages of the past, which are absolutely necessary for the Earth's geological changes.

In trying to solve this difficulty, some have supposed, that the Sun's heat was not so excessive in the past epochs as it is now; and that this insufficiency was furnished by the innate heat contained in the Earth. Since the liberation of energy by the breaking up of radio-active materials has been brought to light, scientists have studied carefully the theory that the appearance of such elements in the Sun, would help to keep up the Sun's heat, and afford it the time required for geological processes on the Earth. Strong reasons have been adduced in the last few years for assuming, that

much of the energy comes from disintegration of the atoms.

With regard to the condition of substances in the heart of the Sun, various ideas are held. All astronomers are of the opinion that the temperatures, in the solar interior, are very much higher than the surface temperature, attaining millions of degrees; and that the pressures caused by the gravitation of the Sun, are also enormously great in the centre. In consequence of the low mean density of the Sun, viz., one-fourth that of the Earth, or 1·4 times that of water, it is quite certain that the Sun is yet in a gaseous condition far below the Photosphere.

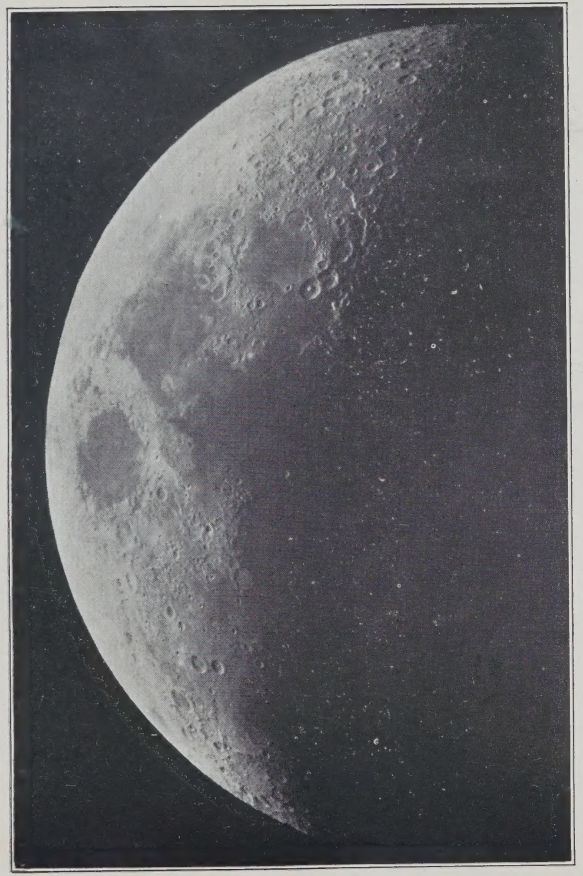
As to the Sun's history, it is, in all probability, somewhat the same as that of our Earth. In the case of the Earth there was first a formless mass of vapours; then the formation of an outer crust; then the internal heat breaking up the crust, here and there, causing earthquakes and volcanoes and the subsequent gradual cooling of the globe, till it became habitable for the creature. Something like this appears to be the history of the Sun; so that Sir Isaac Newton, whose suggestions in physics regarding the laws of light, heat, and motion are being now corroborated through the discoveries of the last two and a half centuries, seems to have been right also in this suggestive question—"Are not the Sun and fixed stars, great Earths vehemently hot?"

LECTURE II.

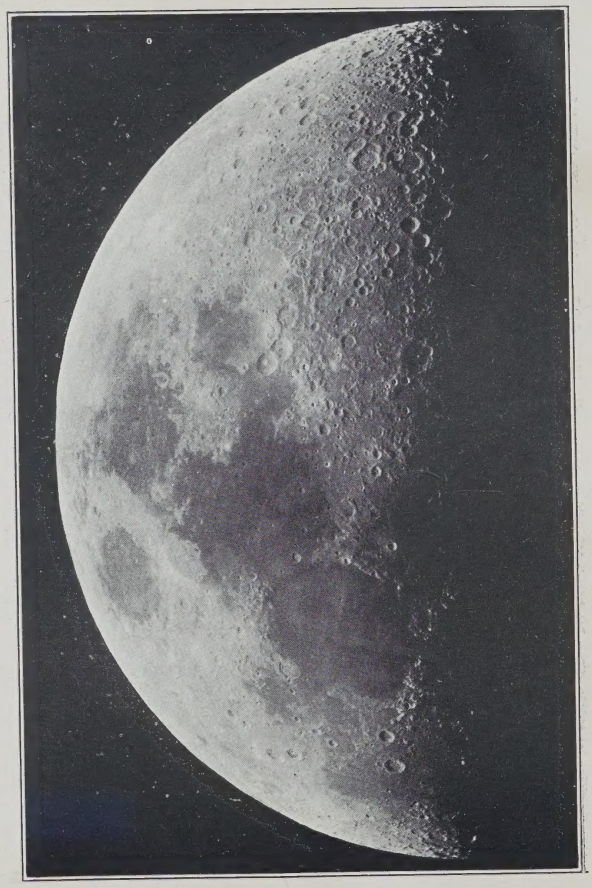
The Moon.

The subject of our lecture to-day is the moon. She is the nearest to the Earth of all the celestial bodies. This is quite apparent, because she is observed to pass in front of many of them, hiding them for a short time. With the exception of the Sun, she interests us more than any of the other bodies. Her frequent changes of position, and her varying appearances or phases, must attract the attention of us all.

The first thing which we cannot fail to notice in regard to the Moon, is her daily motion. This is caused by our Earth's rotating on its axis. She is seen to rise in the east, travel round the heavens westward, and set below the western horizon. Her hours of rising change every day, and the points at which she rises and sets, are constantly varying. She does not always cross the meridian at the same height. Her hours of rising and setting may be best understood by observing her phases. At new Moon our satellite is quite invisible to us, owing to her being between Earth and Sun. When she is two days old she is seen as a little bow in a cloudless sky in the west, just immediately after the Sun has set. When her luminous part is only a narrow crescent, there is a pale, ashy light shining on her face, making all the dark part visible. This is the Earth-light shining on the Moon, for when it is new-moon to us, the Earth is full to a spectator placed on the Moon, and our light shines on the Moon so brightly that it is visible to us after another reflection. As the narrow bow becomes fuller and fuller every day, her time of rising becomes later, and half the illuminated face



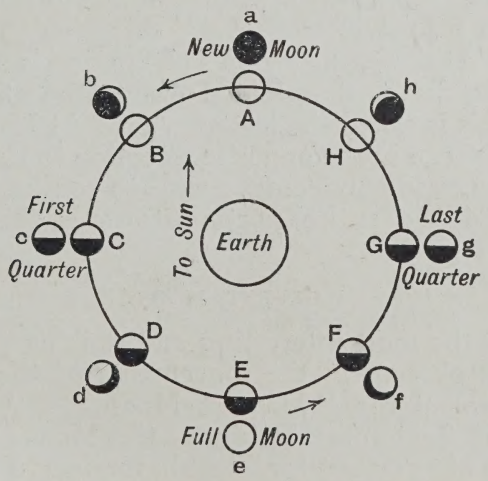
MOON. Age 5·74 days.



MOON. Age 7·75 days.

presents itself as a semi-circle. This phase is called the first quarter. The flat side of the semi-circle grows larger until she has a gibbous face appearance, then a circular disc, because the whole of her visible face is turned towards the Sun. She is then called full Moon. When she appears full she always rises when the Sun is setting. She then begins to wane, first to the half-Moon phase, and so on to a slender crescent. During that time her hour of rising becomes later and later, until she rises for the last time before sun-rise.

Another point to be noticed is, that when the moon at full is always opposite to the Sun, she, when full, must be North of the Equator in winter during the time that the Sun is south of it; and south of the Equator in summer. Consequently, when we have the least sunlight in winter, the Moon, when full, is nearly overhead in the heavens, and affords us more light during that season; while in the summer months she is low in the sky and not so brilliant.



PHASES OF THE MOON

Figure 2

This explanation may be seen more clearly from the diagram (Fig. 2.) The globe in the centre stands for

the Earth. The large ring which encircles the Earth, is the Moon's orbit. The smaller globe exhibited in eight successive positions in the orbit is the Moon; while the Sun is at a great distance beyond A. The small figures a, b, c, d, e, f, g, h, represent the appearances of the Moon relative to the ecliptic as seen from the Earth when in the positions represented by the corresponding letters. At A, a, the Moon is at conjunction; consequently the dark portion is towards the Earth. This is called the New Moon. At B, b, the Moon is a little east of the Sun. A crescent is seen at the western side of the disc, and the horns point eastward. At C, c, the Moon's elongation is 90 degrees. One half of the disc or visible portion is illuminated, while the other half is dark. This is called the first quarter. At D, d, more than half the disc is illuminated, and her appearance is said to be gibbous. At E, e, the Moon is at opposition, and the entire disc is illuminated. This is called Full-Moon. At F, f, one part of the disc is dark, and the Moon is again gibbous; but the bright portion is turned in the reverse direction to that seen at D, d. At G, g, the Moon's elongation is 270°. One half of the disc is illuminated; while the other half is dark. This is called the last quarter. At H, h, a small crescent is seen in the opposite direction to that of B, b. The Moon gradually comes round to conjunction again at A, and the entire portion towards the Earth is dark.

HARVEST MOON.

One of the most interesting and striking phenomena which we observe in the movements of the Moon, is what is called the "Harvest Moon." A few days before the September Equinox, the Moon, when full, rises soon after sunset for several evenings in succession. By doing so, we have several very fine moon-light evenings; and the Moon being above the horizon until early morning, not only shows a lovely appearance, but also prolongs the light, which is very helpful to the farmers during that season. The full Moon that appears

PLATE III. *to face page 32.*

MOON. Age 14 days 1 hour. Showing the systems of rays from the craters Tycho and Copernicus.

From a photograph taken at Lick Observatory.

nearest to September 22nd has long been called the "Harvest Moon," because of the great benefits obtained from moon-light during the harvest. Long before the farmers could understand the phenomenon, the annual appearance of the "Harvest Moon" was observed and looked forward to by them; because the moonlight evenings lasted for a very long time, and they were able, thereby, to work longer during the period of the ingathering of the crops.

The Moon travels towards the east, and comes to the meridian 51 minutes, on the average, later every succeeding night; and if the time between her rising and her arriving to the south were always the same, she would rise, on the average, 51 minutes later every evening. As the solar day lengthens fastest at spring, so the time that the Moon is above the horizon, lengthens most every day when she is crossing the Equator from south to north, as she does annually in September.

The full Moon that appears in October, shows nearly in the same way the strange phenomenon we have mentioned. It is called "The Hunter's Moon," not because it enables the hunter to pursue his game in the evenings, as some people imagine, but owing to the crops having been gathered in September there is nothing to come between the sportsman and his pleasure.

EXPLANATION OF THE PHENOMENON.

The Harvest Moon takes place when the ecliptic or the Sun's apparent path through the sky, is variously inclined to the horizon at different seasons of the year. The celestial Equator is always at the same angle with the horizon, consequently, equal parts come above the horizon in equal periods of time. Were the Moon to travel in the celestial Equator, she would rise and set exactly in the east and west points of the horizon respectively, and she would rise later every night by an almost regular interval. The Moon, however, travels in a path inclined to the ecliptic at an angle of 5 degs. 8 mins. 48 secs., and as the Ecliptic is inclined to the celestial Equator at an angle of 23½ degrees, the Moon

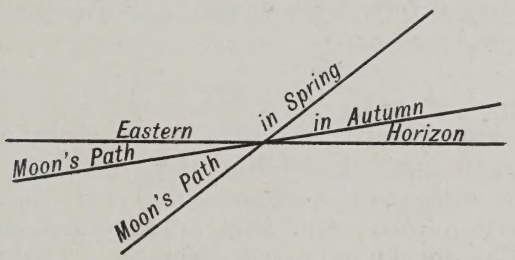
does not rise at equal intervals every successive evening. When the constellation Pisces is in the eastern horizon, the Ecliptic rises with the smallest angle. At the September equinox, the Sun is in the constellation Virgo, and the full Moon being opposite to the Sun, is in Pisces, and rises at sunset. On the night following, though the Moon has moved in her orbit nearly 13 degrees, her path being slightly inclined to the horizon, she will be only a short way below her position at the same time on the preceding evening. The result is that she rises only a little later, and, for several evenings, appears in the east at almost the same hour after sunset. Though the variations in the time of the Moon's rising, are invariably large when she is in or near the constellation Virgo, and small when she is in or near Pisces, *i.e.* every month; yet we usually observe these variations only in September and October. Indeed we do not often notice the Moon's rising, except it be when she rises near sunset or early in the evening. We generally take more notice of the Moon when she is full ; and the Moon can be full in or near Pisces, where the variation in the time of her rising is smallest, only when the Sun is in or near Virgo. But this can only take place at the September equinox. In March, the conditions are the opposite ; and the Moon at her full, rises every succeeding night, later than at any other season of the year. In our latitude, the difference between the hours at which the Full-Moon rises on successive evenings in September, is, on the average, about 20 minutes; while in March the average difference is about 80 minutes. Those parts of the ecliptic which rise with the least angle, set with the greatest ; while those which rise with the greatest, set with the least. Therefore, while in September the Full-Moon rises at nearly the same hour on several successive evenings, the time of setting varies greatly because of the large angle of the ecliptic with the western horizon.

In looking at Fig. 3. you may understand better the cause of the harvest-Moon. When the Sun crosses the Equator travelling southward, the Moon's apparent

path intersects the eastern horizon at a slight deviation, *i.e.*, the Moon, instead of rising with a great inclination from the horizon, rises on a long slant parallel with the horizon. In consequence of this, the full Moon rises, for several successive evenings, at nearly the same hour immediately after sunset.

MOON'S NODES.

A word may be said regarding the Moon's nodes. The nodes are those points in her orbit, at which she crosses the plane of the Earth's orbit or ecliptic. The



MOON'S PATH AT EQUINOXES

Figure 3

point of intersection in which she passes from the south to the north side of the ecliptic, is called her ascending node; while the point of intersection in which she passes from the north to the south side of the ecliptic, is called her descending node. These nodes do not occupy fixed positions on the ecliptic. They gradually change their place, moving from east to west. The period in which they perform a complete revolution on the ecliptic, is 18.6 years, or at the rate of 3 mins. 10 secs. per day. When the Moon's ascending node is in or near the constellation Pisces, or the Vernal Equinox, the time between the successive risings, will be still more shortened. The harvest Moon will then be most serviceable to the farmers.

THE LINE OF APSIDES.

The elliptical path of the Moon changes slowly every month. We have seen that the plane of the

Moon's orbit shifts its position, owing to the fact that the nodes of the orbit perform a retrograde revolution on the ecliptic in 18.6 years. But, in addition to this shift, the axis major of the elliptic orbit of the Moon changes its position slowly in the plane of the orbit, making an entire revolution from west to east in 8.85 years. This is equal to 6 mins. 41 secs. daily. When the Moon is at her nearest approach to the Earth she is in perigee, and when she is farthest from us she is in apogee. The line joining the perigee and apogee is called the line of the Moon's Apsides; and the phenomenon referred to is called the progression of the Moon's Apsides.

VARIATIONS OF MOON'S DISTANCE.

When the Moon's distance is carefully measured from time to time, it is found that her distance from the Earth varies to the amount of several thousands of miles every month; and that amount coincides with the variation in her apparent diameter. Owing to her varying distance, she sometimes appears about 12 per cent. larger than she does at others. Her greatest distance from us is 253,000 miles; her nearest is 222,000 miles; while her mean distance is 239,000 miles. When she is at her greatest distance from us her disc measures 33 mins. 33 secs.; when she is at her nearest distance her angular diameter is 29 mins. 23 secs. From these changes in the apparent angular diameter, we conclude that the Moon's orbit is not quite a circle, but flattened to a small extent, thus forming an ellipse or oval, the centre of the Earth occupying one of the foci.

MOON'S ROTATION PERIOD.

A very important point to be noted in the Moon's motion is, that she turns round on her axis in exactly the same time that she goes round the Earth; so she always shows the same side to us; consequently we never see her other side. Some would infer from this that she does not rotate upon an axis as the Sun and planets do. But, the fact that she always turns one

face towards us, is sufficient proof to us that she does rotate upon an axis. The rotation, however, takes place so slowly, that she only turns round once during the time in which she revolves round the Earth. Our Earth, on the other hand, revolves on its axis thirty times more swiftly than our satellite does. If, for example, you put a terrestrial globe in the centre of a round table, and walk round it, always keeping your face towards the globe, you will find that when you have made one complete turn round the table, you will have made your body turn once round upon itself. Similarly, the Moon goes round the Earth. She keeps the same face always looking towards the Earth in the course of her movement round it. The late Dr. Denison uses the following apt illustration to elucidate this point. Were a man waltzing with a small girl, each of them would turn round the other on their own axes, facing each of the four corners of the room in succession. Further; the man being heavier than the girl, would make a smaller circle round her than she would make round him; that is, he would swing her round him. On this simple analogy, we thus see that the Earth revolves round the Moon, just as the Moon revolves round the Earth.

LIBRATIONS OF MOON.

Notwithstanding the fact that the Moon always presents the same face to us, it is found that she rolls a little in her orbit, sometimes showing a little of her right side; while at other times she shows a little more of her left side. These periodical oscillations are called Librations. As the Moon's Equator is inclined 6 degs. 44 mins. to the plane of her orbit, it follows, that once every month, her north Pole leans 6 degs. 44 mins. towards us; while a fortnight later her south Pole leans in a similar way. This phenomenon is called the Moon's Libration in latitude.

As the Moon's orbit is an ellipse, it follows that her motion in her orbit is variable, the reason being that she is slower when she is at her greatest distance from

the Earth, and faster when she is nearest. Her motion of rotation on her axis however, is quite constant. This produces what is called Libration in longitude. In consequence of this Libration, we can see at one time a little more of the eastern side, and at another time a little more of the western side. Its greatest amount is 7 degs. 45 mins.

LUNAR ECLIPSE.

When the whole surface of the Moon in her journey round the Earth, comes exactly opposite the Sun, or nearly so, she passes through our shadow. Then a lunar-eclipse takes place. This can only happen when the Moon is full. An eclipse is partial when only part of the Moon's surface passes through the border of our shadow. If the plane of the Moon's path coincided with that of the Sun's path, we should have an eclipse at every full Moon. But it generally happens that the Moon, when full, is either slightly above or below the plane of the Sun's path. Consequently, she fails to pass through the shadow of the Earth. It is only at intervals of six months that eclipses of the Moon can happen; that is, when she crosses the Sun's course in two opposite points of the sky, called the Nodes of the Moon's orbit. It is always considered a sight of more or less interest according as the eclipse is partial or total. To the observer who has got a clear sky, a total eclipse is a very impressive sight. Slowly and steadily the shade creeps on over the lunar mountains and plains. The darkness gives place to a coppery tint; and when the whole surface is covered, the Moon presents the appearance of a penny fresh from the mint. By some ancient nations, the Moon was supposed to be in pain when she was eclipsed. In order to relieve her fancied distress, they lifted torches high in the air, blew horns and trumpets; and even after the eclipse was over they offered sacrifices to the Moon. The opinion also extensively prevailed that witches could, by their charms, darken the Moon and bring down an influence on the Earth for evil.

In solar eclipses, the Sun was supposed to turn away his face in abhorrence of some great crime. The Chinese, too, have been great observers of eclipses from remote antiquity. Though they did not take much notice of those of the Moon, they regarded eclipses of the Sun as unfortunate, especially those which happened on the first day of the year. These were supposed to forebode calamity to the emperor who, on such occasions, did not receive the usual compliments of the season.

MEASURING THE MOON'S DISTANCE.

The Moon is the nearest of the heavenly bodies to us. The mathematical principles required in determining her distance, are similar to those employed by a surveyor in measuring the width of a stream which he cannot cross, or in determining the distance of an inaccessible object. The surveyor measures off a base line of a certain length, from two ends of which the object is seen. After doing so, he measures at each end the angle included between the other end of the line and the object. He thus obtains a triangle. From it he learns the size of one side and two angles, and from these he can easily find the other parts.

In order to ascertain the Moon's distance, we measure its distance from the zenith at two Observatories, such as Greenwich and the Cape of Good Hope, which have about the same longitude, but are widely separated in latitude. As the latitudes of these Observatories are well determined, the base line, which is the line drawn from one Observatory to the other and which may be several thousand miles in length, is also known. Hence, this great triangle, formed with the Moon at the apex and the Observatories at the angles at the base, can be calculated in a similar manner to the method employed by the surveyor who uses a base line which may be only a few miles in length. The result shows the average distance of the Moon to be about 239,000 miles away. This actual distance being ascertained, we have found her mean apparent

diameter to be 31 mins 7 secs. This measurement gives an actual diameter of 2163 miles, and is equal to 0.273 of the Earth's diameter.

MOON'S MASS.

The quantity of matter composing the globe of the Moon, amounts to $\frac{1}{81}$th part of that of the Earth. Consequently, bodies on her surface are much lighter than they are on the earth. The proportion is one-sixth. A man weighing 180 lbs on our planet, would weigh only 30 lbs. on the Moon.

MOON'S ATTRACTION.

Her attraction towards the Sun is considerably greater than that towards our Earth; and if, when placed between our brilliant orb and the Earth, she were suddenly stopped in her orbit, she would depart from the Earth and fall into the Sun.

MOON'S INFLUENCE UPON THE EARTH.

The proximity of the Moon to the Earth causes her to exercise a powerful influence upon our planet. Although the other planets in the Solar System and the distant stars were obliterated, we would not be inconvenienced thereby; but if our satellite were wiped out of existence, the consequences to our shipping would be very disastrous indeed. The maritime commerce of the world would be completely disorganised; for the Moon is the chief agent in causing the tides. The Sun, of course, produces tides on the Earth; but his influence is only equal to about two-fifths of that of the Moon. This seems to contradict what has just been said, that "the Moon's attraction towards the Sun is considerably greater than that towards our Earth." The two statements however are quite reconcilable, because the the gravitational pull is the product of the masses divided by the inverse square of the distance. Hence, the result is, that the gravitational pull of the Earth on the Moon, is approximately half of the gravitational pull of the Sun on the Moon. But the tide-raising

forces vary as the inverse cube of the distance, and directly as the mass of the tide-generating body. The tide-raising force of the Sun is therefore 25·5 million times stronger than that of the Moon, on account of his greater mass; and 59 million times weaker, on account of his greater distance. The Sun's tide generating force is consequently about $\frac{25.5}{59}$ or a little less than half of the Moon's.

If the Moon produces tides upon our planet, it necessarily follows that our planet must, in like manner, exercise a powerful influence upon our satellite.

The late Sir George W. Darwin found, in the course of his investigations, that the tides, in going from east to west in the opposite direction of the Earth's rotation, act by their friction as a brake on its motion, just in the same way as a brake acts upon a machine. They tend to slacken the Earth's motion of rotation on its axis. The consequence is, that the day is becoming gradually longer by the action of the tides slowing down the speed at which our planet is rotating. The Moon's orbit is becoming enlarged, and its period of revolution is being lengthened. Darwin's researches show that after an immense period of at least 150 millions of years, tidal friction will equalise the periods of rotation of the Earth and Moon; and the day and month will be of equal length, viz., 55 of our present days. When that time arrives, our planet, in its revolution round the Sun, will always turn the same face towards our satellite in the same way as our satellite does towards our Earth. The tides are due to the fact that the Sun and Moon attract the portions of the Earth nearest to them, more powerfully than the more remote portions. This of course causes friction on the Earth as she revolves.

Darwin concluded from his investigations, that there was a time when the Earth was rotating between three and five hours, and that at this epoch the Moon, being much closer to the Earth than she is now, was revolving round our planet in the same time that the Earth rotated. It is probable that our planet and satellite,

then in a liquid condition, had been revolving almost in contact with each other; but the action produced by the solar tides caused the Moon to recede gradually from the Earth, until she reached her present distance of 239,000 miles. The Earth, by reason of her overpowering attraction and the great tides which it raised in the plastic globe of the Moon, stopped the Moon's rotation relative to the Earth; *i.e.*, the Moon revolves round the Earth in the same time that she rotates on her axis. The time of close contact of Earth and Moon probably marked the birth of the Moon. The supposition is, that she was detached from the Equator of our planet owing to her very swift period of rotation of three or four hours, and also because of the very great force of the solar tides. The result of this was, that five thousand million cubic miles of the Earth's mass left the surface of the Earth. The time when this took place was, according to Darwin's calculations, 55 million years ago.

The theory of tidal friction obviously explains why the Moon always turns the same face to the Earth. When we take into consideration the fact that the Earth's mass is 81 times that of the Moon; and that its radius is four times as great, the Earth's tide-raising force on the Moon is more than twenty times as great as the Moon's force on the Earth.

Applying this principle to the planets, it is obvious that the solar tides have a stronger pull on the planets nearer the Sun, than on the more distant ones. As to our Earth, the outcome of solar tidal friction will be to slow down its rotation, and thus lengthen the day to a greater extent. The Earth's day, being then longer than the month, the effect of the Moon's pull will be to tend to accelerate the movement of the Earth. The law of conservation of angular momentum in the Earth-Moon system thus involves a diminution in the Moon's contribution, so that the Moon must again approach the Earth.

MOON'S ATMOSPHERE AND TEMPERATURE.

Let us now turn our attention to the Moon's atmosphere and temperature. We have merely to look at the Moon with the naked eye, to be convinced of the fact that she has no atmosphere of any appreciable kind, although it is supposed by some observers, that there are indications of a very rare atmosphere in some of the deepest depressions of the lunar surface. Were her atmosphere as dense as that of our own planet, large portions of her surface would be darkened by clouds. It has also been found that when the Moon occults a star, the star immediately disappears at the edge of the Moon, and as quickly emerges from her other edge. It has also been discovered that, at a solar eclipse, the edge of the satellite is quite dark and sharp upon the solar disc. From these facts, we must conclude that there is no water and no appreciable atmosphere upon the Moon.

The late Dr. Johnston Stoney worked out a clever theory to explain the reason of there being no atmosphere on the Moon; and indeed to show how any small planet may slowly but surely be deprived of its atmosphere. His theory is founded upon the dynamical theory of gases. According to that hypothesis, all the atoms or molecules composing a gas, are in continual and rapid motion. Some of the atoms move as speedily as a rifle ball; while others move more slowly. Were there no resisting force, these molecules would rush on, and the gas would soon be scattered and lost. So far as a planet's atmosphere is concerned, the force of gravity is the force which overcomes the velocities of the atoms and prevents them from rushing off into space. The Major planets exert a more powerful attraction on their atmospheres than the inferior planets; consequently, the heavy gases such as carbonic acid, are more strongly attracted than the lighter gases such as hydrogen, nitrogen and oxygen. Dr. Stoney supposed that the velocities of the atoms of hydrogen, nitrogen, and oxygen are so high that if in

the past ages these gases existed on the Moon, the Moon's gravity would not be strong enough to resist their velocities. All the molecules would speedily rush off into outer space, and would never return to the satellite. It is probably owing to this fact that the Moon has little or no atmosphere. Professor Pickering estimates, that for every three and one-half-miles that we ascend, the density of the Earth's atmosphere is halved; and at a height of 50 miles it is equal to that at the Moon's surface. There is no doubt that free hydrogen is rushing from our Earth into outer space; but the process is very slow compared with what obtains on the Moon, owing to the Earth's mass being greater than that of the Moon.

LUNAR TEMPERATURE.

As regards the lunar temperature, her night-side must be equal to that of interplanetary space, supposed to be almost equal to absolute zero, or—273° Centigrade. It is impossible to determine the temperature of the day-side under a vertical Sun. Professor Langley thought it might be near freezing point. As the result of his researches on the lunar spectrum, he supposed that the temperature must be very much below that of boiling water. It is safe to assume that when the Sun is overhead, the lunar temperature may probably be between the freezing and boiling points of water; the presumption being that it is more near the former.

MOON'S INFLUENCE ON THE WEATHER.

Another point which calls for some explanation is the influence which the Moon is supposed to exercise upon us and upon the weather. Many people are firmly convinced that changes in the phases of our satellite cause changes in the weather. If, for example, the weather be bad at new-Moon it will be good at full, and vice versa. Now, the only way in which our satellite could influence the weather would be by

variations in the amount of heat which she sends to us. It has been calculated, that the full Moon radiates only $\frac{1}{450,000}$th part as much as the Sun. It is absolutely impossible that such an infinitesimal amount as that, could have the slightest effect on our planet. Meteorologists find from this mode of observation and inquiry, that these ideas held regarding the influence of the lunar phases on the weather have no foundation in theory, and are not in accordance with observed facts. In primitive times the opinion was firmly held, that the light of the Moon affects the minds of people, hence our English words "lunatic" and "lunacy," from the Latin word "luna," the Moon. Even at the present day there is a popular notion held, that the Moon exercises an influence over human maladies. It is also supposed by many agriculturists that, before they can succeed in raising fruitful crops, they must sow at a certain time in spring according to the proper phase of the Moon. They also believe that if they are to receive in any adequate measure the products of the ground, they must commence the harvest, and gather in the crops, at times and under circumstances regulated by the appearances of the Moon. Such ideas are mere superstitions, and have not a shadow of proof.

MOON'S PHYSICAL APPEARANCE.

We shall now consider the Moon as she is disclosed to us by the aid of the telescope. The markings we see on her face, become extremely interesting as we view them with powerful telescopes. On account of her nearness her surface has been carefully examined with these, and has been found to be very uneven and broken, far more so than that of the Earth. Valleys are apparent, and they are surrounded by circular margins of a kind to which nothing on Earth can be likened. The lunar mountains are exceedingly numerous, especially in the southern portion. They are mostly of a circular or cup-shaped form, varying in height from 1000 to 23,000 feet. They are best observed five or six days before and after new Moon. Their shadows are then

cast prominently on the ground. At the time of full-Moon, the Sun is shining overhead on the satellite; and the shadows of the mountains are not seen. The Peruvians invented a story to the effect, that the markings on the Moon were occasioned by a beast of the forest who, being in love with that luminary, climbed up to it and dirtied it with his paws! Even before the invention of the telescope, mankind had not waited for Galileo before forming the very notions of the Moon that we moderns are so proud of entertaining to-day. Democritus attributes its spots to the shadows of mountains and hills; and its support and motion were philosophically, though not very scientifically, explained by Anaxagoras, and by others of the old Grecian schools.

With the help even of a small telescope, the lunar surface presents a varied and striking appearance. It is a comparatively easy matter for us to make a map of the part that we see; in fact we know more about the Moon than our forefathers did about some parts of our own world. It would have been much easier for them to make a map of the Moon than a map of the interior of Africa and Australia. Of all the heavenly bodies, the Moon is the one of whose physical constitution we can learn most. A telescope that magnifies 1200 times, would enable us, at the distance of the Moon, to see as a visible point on the lunar surface, an object whose diameter is 300 feet. Such an object would be no bigger than many of our public buildings. And so, if such edifices were really on the Moon, they might be detected on a minute inspection. If a multitude of living creatures such as an army, were moving over the lunar surface in a large body, such a gathering might be detected by a difference in shade or colour. To find out such minute objects the surface of the Moon would have to be divided and distributed among one hundred observers. Each of them would have a particular spot assigned to him, and he must prolong his observations for thirty or forty years or so. But nothing of this kind need be expected; for the largest telescopes reveal to us the fact

that the Moon is a desert without visible movement, where the eternal silence remains unbroken.

LUNAR MOUNTAINS.

The face of the Moon which we see, shows at least ten great mountain ranges. The lunar Alps and the Apennines are immense mountain ranges. Among the former, there are many hundreds of peaks, one of which, called Mont Blanc, rises to a height of 12,000 feet; while others reach from 5,000 to 8,000 feet. The Apennines, however, are by far the most magnificent range in the visible surface, including 3,000 peaks, and extending in a nearly unbroken curve of 640 miles in length. The great headland rises 15,000 feet; while another, on the south-east, is 14,000 feet. The western Apennines extend for 184 miles from east to west. The eastern Apennines are the highest portion of the great Apennines mountains.

MEASURING LUNAR MOUNTAINS.

Although we cannot go up to the Moon to measure it, it is possible for us to find out the actual height of a lunar mountain. We can determine its altitude by measuring, with a micrometer, the length of the shadow cast by the mountain when it is illuminated by the Sun's rays. The length of a shadow cast by these rays, depends upon two things, (1) the height of the object which causes the shadow, and (2) the elevation of the Sun at the time. When the Sun is at its highest point in the heavens at noon, shadows are short ; but as it declines towards its setting they lengthen out. When we compare this measurement with the angle subtended by the Moon's diameter, we can calculate the length of the shadow in miles.

In addition to the mountain ranges, there are a great many detached peaks, more than 10,000 cracks, and 32,000 craters, most of which have been mapped and named.

CRATER PLATO.

One of the best examples we find of volcanic activity on the Moon, is the huge crater Plato. Its floor is a smooth plain, almost level, and is about 60 miles in diameter. Additional interest is given to this crater, owing to the fact that it is marked with a large number of small volcanic cones, which vary in diameter from one half mile to little more than one mile. Between 40 and 50 small craterlets are mapped.

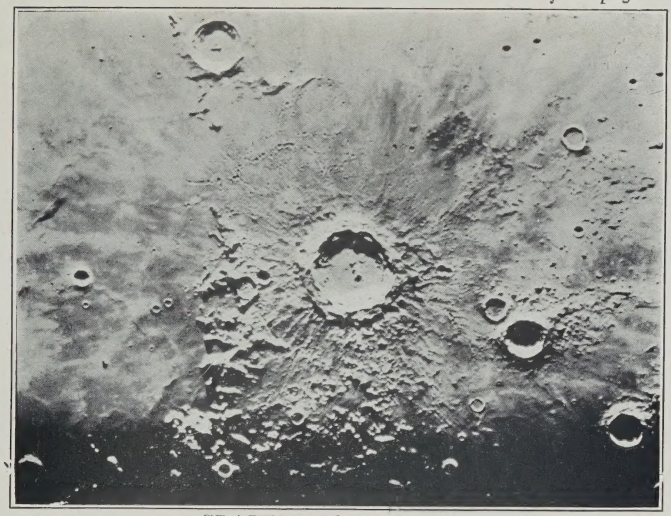
When we look at a photograph of the full-Moon, we cannot fail to notice three bright regions of considerable extent. There are also seen many small bright ones connected with mountain peaks and craters. An immense number of bright streamers encircle these large craters, and emit rays in every direction for hundreds of miles.

CRATER TYCHO.

The most prominent one of the three regions is the crater Tycho. It is 54 miles in diameter. The streamers radiating from it extend as far as the Moon's Equator. All this region is found to be composed of elevated and mountainous peaks rising both on the east and west, to a height of 17,000 feet.

CRATER COPERNICUS.

Another very bright region is the crater Copernicus. The nature of the streamers is seen very clearly, but they do not become distinctly visible until the day before full-Moon. Copernicus is one of the finest craters on the Moon. It is nearly circular, and is 55 miles in diameter. When it is observed under a zenith Sun, the shadows of its walls and central mountain are not seen. But the inner terraces, and the wonderful system of white streamers in the centre of the crater and extending in all directions to vast distances, are very distinctly visible.



CRATER COPERNICUS.
Photographed at Yerkes Observatory by Prof. Ritchey.

SEAS OF SERENITY AND IMBRIUM.
From a photograph taken by Prof. Ritchey, Yerkes Observatory.

CRATER ARISTARCHUS.

The third celebrated crater is Aristarchus. It is 29 miles in diameter. It forms, with its companion crater Herodotus, 23 miles in diameter, one of the most striking objects which the telescope has revealed on the visible lunar surface. This is not owing to its size, but to its remarkable whiteness.

Many other prominent craters might be mentioned; the most important of which are Gassendi, Archimedes, Ptolemæus, Alphonsus, Arzachael, Petavius, and Theophilus. The first of these is 55 miles in diameter, with walls and peaks rising from 5000 to 9000 feet above the floor. The second is 50 miles in diameter, with a massive border rising 4000 feet above the interior. It is remarkable for its crater cones, craterlets, pits, white spots and light streamers. The third is the largest walled plain on the Moon's visible surface, 115 miles in diameter. Its walls and peaks rise 6000 to 9000 feet above the interior. The fourth is 83 miles in diameter. The fifth is 65 miles in diameter, with massive border rising from 7000 to 13,000 feet above the floor. The Sixth is 78 miles in diameter, within which is a massive central mountain, rising at one point to a peak 6000 feet above the floor. The seventh is 64 miles in diameter, and is enclosed by a great rampart tower, rising on the west to a stupendous cone 18,000 feet above the bottom of the crater.

LUNAR CRACKS.

The telescope also reveals dark, narrow lanes. These are unquestionably cracks on the lunar surface, and might be termed canals. A striking example is found in the western portion of Alphonsus. These cracks are naturally caused by the extremes of temperature to which the surface is exposed. At the junction of several of the lines there are spots of various sizes which might be termed oases, such as we find on the crater Eratosthenes, 38 miles in diameter. On account of the Moon's proximity to us, these lines and spots are much more easily seen than those on the planet Mars.

LUNAR SEAS.

There are also dark regions which, from Galileo's time, have been called seas; although this is somewhat of a misnomer, as it is a well known fact that they have been absolutely dry for millions of years. Professor Campbell is of the opinion, that "many of them are overflowed areas, just as immense terrestrial areas were overflowed by molten lava; and that they contain remnants of many craters, in which only the summits of the crater rims continue unsubmerged." There is, for example, Mare Crisium 355 miles long by 281 miles broad. On the eastern rim, submerged craters and flow marks are quite noticeable. Mare Serenetatis is a wide and beautiful plain nearly circular, 433 miles in length by 424 miles in breadth. Mare Nubium is 225 miles in diameter, and is surrounded by ringed plains. Many submerged craters are visible. Mare Tranquilitatis is 300 miles in diameter, while Mare Imbrium is 240 miles long by 210 broad.

ORIGIN OF VARIOUS LUNAR FEATURES.

And now a few words in closing, in explanation of the origin of the various features on the Moon's surface.

Regarding the origin of lunar craters, we may at once dismiss the theory of Professor See, and some other astronomers and geologists, that they are the holes made by huge meteors falling into them millions of years ago as the result of collision when they were travelling round the Sun with planetary speed. As far as our investigations go, there is no evidence in favour of the theory that those craters have a meteoric origin. The only crater known that has been found in this way upon our own planet, is that at Arizona U.S.A., and it has no central peak.

Those who favour the meteoric hypothesis, urge that a large number of the craters have central peaks, varying in height from 3000 to 7000 feet; and they attribute these peaks to reactions from the collisions. It is no doubt true that there are numerous peaks; still it is found that most of them have no central ones. Pro-

fessor W. H. Pickering states that central peaks are seldom observed in craters less than four miles in diameter. In many of the craters several peaks are seen near the centre; but there is no central one. Lofty volcanic cones, containing small crater openings at the summit, have been seen on the Moon. Pickering has observed some small craters at the tops of central peaks in large craters. He says that "outside of the craters, there are many examples of high peaks, which carry minute summit craters less than one mile in diameter, and are analogous to terrestrial volcanoes." The fact that small craters exist at the tops of large central craters, is a strong argument against the meteoric theory; while on the other hand, it supports the theory of the volcanic origin of these peaks.

The supporters of the meteoric hypothesis urge further, that the floors of the craters are far below the level of the tops of the crater borders and also the plains surrounding them. It is supposed by them, that the great force of meteors have made hollow cavities, causing deep craters interiors, and projected the materials upon the adjoining regions. It is scarcely possible that a huge meteor would be powerful enough to form a crater 60 miles in diameter, thousands of feet deep, in several seconds of time.

A more plausible theory, and one which is generally accepted by astronomers is, that the lunar craters came into existence as the result of violent volcanic action in the past, much in the same way as the volcanoes which have been formed on our own planet. Professor Campbell, in his article on the problem of the origin of Lunar craters says, "Whatever the beginnings of a volcanic lunar crater may have been, there comes a time, probably early in its history, when the interior fills with molten materials, which well up through the central duct or neck that leads down to a considerable depth in the lunar body. This molten material overflows the rim of the crater, building up the rim, increasing the outer diameter of the rim structure; and some of the molten materials flow out upon the sur-

rounding areas. The exterior walls of the rim cool and solidify, whereas the interior walls liquify from contact with the sea of molten matter, and the interior diameter of the crater ring increases. These processes probably continue intermittently through long ages of lunar evolution. The molten sea of matter lowers in level through the withdrawing of the materials into the Moon's interior. This is a process observed frequently in active terrestrial craters. The filling of the crater bowl probably occurs a great many times, with consequent overflowing and upbuilding of the rim and the increasing of its diameter, by the melting down of its interior wall. Toward the end of the major stage of volcanic activity, the successive fillings of the crater bowl probably are less and less complete, leading, in many cases, to the formation of terraces on the inner wall of the rim. When activity ceases, the floor of the crater is left comparatively level. In many craters the volcanic activity is again renewed, but on a minor scale, with the effect that the central peaks are built up by the escape of volcanic materials from the summit craterlets which terminate the central ducts or necks leading down into the body of the Moon."

As regards the cause of the terracing on the inner side of the lunar craters referred to by Professor Campbell, it is doubtful if these represent the levels of lava at different times. The more probable supposition is, that they represent landslips caused by the undermining action of lava. Telescopic examination seems to bear this out.

When we compare these lunar features with the terrestrial, the most natural conclusion regarding them is, that they are the result of evolutionary processes of an entirely geological nature.

There are difficulties in the way of finding a sufficient explanation for the bright streamers which radiate from the most conspicuous craters Tycho, Copernicus, Aristarchus, Kepler and others, and which run in remarkably straight lines for hundreds of miles over level plains, crater bottoms, crater walls and mountain

structure. Nasmyth, and other astronomers, considered them cracks which became filled up at a later age with material of a light colour, just as we find quartz filling up rock veins.

Others assume that they are meteoric splashes or volcanic projectile discharges from craters. As the force of gravity at the surface of the Moon is only $\frac{1}{6}$th that at the surface of the Earth, the liquid dust particles, discharged ages before from the then active craters, would encounter little or no atmospheric resistance. Consequently, they would travel with a velocity sufficient to carry them hundreds of miles over a large surrounding region of the Moon, where they are now observed. It is probable that the volcanic eruptions which took place in the craters just mentioned, could discharge material with a velocity sufficiently great to carry them to the furthest boundaries of the systems of radiating streamers.

From recent experimental photographs which have been taken of the Moon in light of different wave lengths, on examination it has been found, that there is a deposit of sulphur and iron close to Aristarchus and the other lunar craters.

Professor W. H. Pickering and some other skilful astronomers have affirmed, that they have actually observed changes on the lunar surface, especially near the small crater Linne, which is east of Mare Serenetatis, and is six miles in diameter and 1000 feet deep; while others declare that no changes of any kind have ever been detected. Pickering also asserts that many spots change greatly in appearance during the lunar day. He and others also affirm that small changes of colour occur frequently, near some of the craters; while others have attributed these to causes connected with the cones. As there is no atmosphere, the gases that might be released would be deposited as snow or hoar frost during the long lunar night, and dispersed during the long lunar day. Their behaviour in this way, would explain the observed changes in appearance.

The majority of observers are of the opinion that the lunar surface is a dry, barren waste of rock and debris, covered over with a deposit of meteoric dust, similar to that discovered on the sea bottoms; while a few regard it as covered with a thick deposit of ice. The Moon is certainly a dead, lifeless world, a world which has no weather such as we understand the term, and where nothing ever takes place in the nature of physical and periodic change.

LECTURE III.

Inferior Planets.

We must now turn our attention to the various members of our solar system.

The Sun attracts to itself as a common centre all the bodies that go round it. As these bodies, which we call planets, are in motion round the Sun, it is their tendency to fly off from it. They would do so by reason of a centrifugal force; but the Sun retains them in their courses by what is called a centripetal force. Our Earth and the other planets do not go round the Sun in perfect circles. Their paths are called their orbits. These have the form of an ellipse or oval, i.e., they are longer in one direction than in another. This is how you would describe an oval or ellipse on the ground. Put two sticks A and B into the ground. Throw a piece of string loosely round them. Then take a tool and pull the string tightly all round, making a mark on the ground as you go along; and when you have come round to your starting point, you will have described an ellipse, of which A and B are called its foci. If we imagine the Sun to be placed in one focus A, and the planet to be moving on the line drawn round our imaginary Sun, we shall understand the way in which the orbit of the planet is described.

OUR OWN PLANET THE EARTH.

Take a few simple facts to begin with, to help us to realise the situation with which we are to deal.

Our Earth is placed at a distance of about 93,000,000 miles from the Sun. A wild pigeon is one of the swiftest birds that fly; its speed being about two miles

a minute. Yet it would take a pigeon, if it could keep on at its utmost speed, 100 years to go from the Earth to the Sun. The Earth is a vast globe or ball. Suppose you take a rope and pass it round the globe, you would find the rope would measure 25,000 miles around.

Again, suppose you could put a stick through the middle of the Earth, as you would put a stick through an apple, the stick would require to be about 8000 miles long. If a man were to travel 50 miles a day, it would take him 500 days to travel round the Earth. It is impossible for a man to go through the centre of the Earth; but if he could do so, and could travel at the same rate, it would take him 160 days to go through the interior from one surface to the other.

Our Earth and each of the planets turn round on their axes. To understand this, suppose you were to put a stick through an apple and call the stick the axis; then, if you turn the stick round, you see the apple turn with it, i.e., the apple turns round on its axis. Just so the Earth turns round on its own axis every day. Some of the planets turn round on their axes in a shorter time. Now, suppose you take an apple and tie a string to the stem of it and whirl it around your head. Call the circle or path in which the apple flies its orbit; then if you whirl it swiftly, say 150 times a minute, round your head, the apple would be said to go round in its orbit at that particular speed. The planets go round the Sun in their orbits, just as the apple tied to a string flies round your head. Some of them are nearer the Sun than others, and having a shorter distance to travel, and their actual speed being greater, they complete their journey in a shorter space of time.

As inhabitants of our own particular planet the Earth, the distance we travel in a year is truly wonderful. We go through space at the rate of more than 60,000 miles an hour, or more than 1,100 miles a minute. Yet how utterly unconscious are we of such a flight. This has been going on for thousands of years with such smoothness and regularity, that successive races of men have lived and died unconscious of the

slightest motion on the part of this apparently stable world. Can we conceive of anything comparable to this in the marvellous smoothness of its motion, and is there not here ample evidence of the perfection of the Creator's work ?

PROOFS OF EARTH'S GLOBULAR FORM.

One or two simple things might be mentioned regarding this great globe suspended in space. As to the globular form of the Earth, two or three simple proofs might be stated.

1. The shape of the shadow cast on the Moon in an eclipse, is a perfect segment of a circle, and this is the shadow of the sphere on which we live.

2. Vessels passing out of sight at sea disappear, just as they would if they were descending the brow of an hill; first the hull disappears, then the lower part of the masts becomes invisible, and then the top masts go out of sight.

3. People have sailed round the world. Magellan was the first to accomplish this; then Sir Francis Drake; and for long years it has been a very common thing for Australian vessels to sail in an easterly direction, and return by continuing their eastward course, and so complete the circle.

The diameter of the Earth is about 8000 miles, and thus any inequalities in its surface, bear a very small proportion relatively, to the the size of the world. The highest mountain in our world is only five miles in height. That is only the sixteen hundredth part of the Earth's diameter. So, if you made a globe a foot in diameter to represent the world, the mountains on it would only be represented by grains of sand. The deepest mine would be a very small scratch with a pin.

SEASONS.

The subject of the Seasons may also be alluded to, as they bear on the same point. In summer, the Sun appears nearly over our heads at noon. Look at your

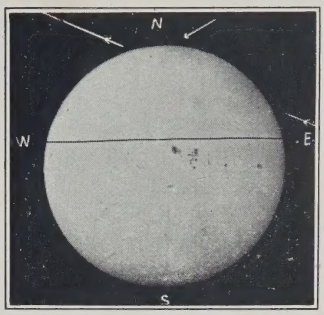
shadow on a summer's day, and see how short it is. In winter, if we look at the Sun, we see it very low in the sky, and our bodies cast a very long shadow. In summer, the Sun is seen to cast down his rays in a perpendicular manner; while in winter it sends them to us in a very slanting direction. Thus it is that the perpendicularity of the rays of the Sun which gives the maximum of heat, causes summer; while the slanting of the rays of the Sun causes winter. It is all owing to the oblique position of the Earth's axis. If this were perpendicular to the plane of our path round the Sun, there would be equal day and night everywhere all round the world. This peculiarity of our Earth is not common to all the planets. Such a planet as Jupiter, for instance, has its axis very slightly inclined to the plane of its orbit. The consequence is, that it can have very little change of seasons.

There is a difference of 3,000,000 miles in the distance of the Sun in summer compared with winter. In summer, its aphelion distance is 94,000,000 miles; while in winter it is 91,000,000 miles. This variation in the Sun's distance, is due to the fact that the Earth's orbit round the Sun is an ellipse, and the Earth is nearest the focus, the Sun, on December 31st, reaching its greatest distance about July 1st.

We may now take leave of our planet and turn our attention to Mercury and Venus. These are termed Inferior planets, because their orbits lie between us and the Sun. Mars, Jupiter, Saturn, Uranus and Neptune are named Superior planets, because their orbits are outside that of our Earth.

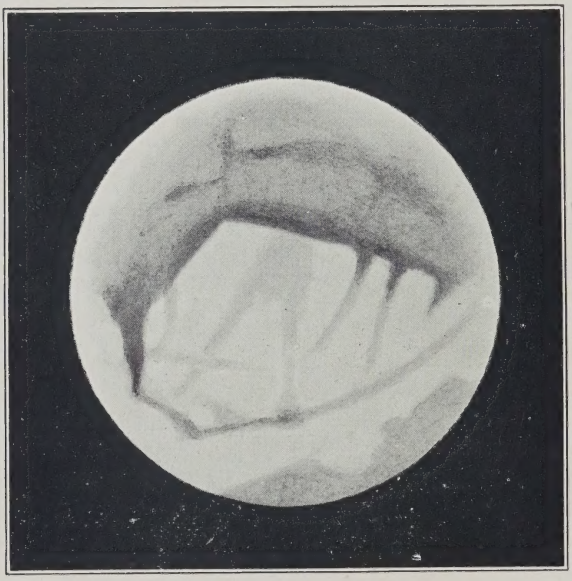
MERCURY.

Mercury lies so near the Sun, that he is seldom seen with the naked eye. He never rises much before the Sun, and never sets much after him, keeping always very close to his gigantic neighbour. If observers know when he is going to be at his greatest distance east of the Sun shortly after sunset, and west of the Sun shortly before sunrise, they will have no difficulty in seeing the



TRANSIT OF MERCURY. VENUS SHOWING CRESENT PHASE.

Photographed by Professor Barnard, Yerkes Observatory.



MARS.

Drawing by Professor Keeler, Lick Observatory.

planet as a first magnitude, ruddy star low down in the sky, and small telescopes will show the planet's disc.

The nearer a planet is to the Sun the stronger is the attraction and the more rapid is the planet's motion in its orbit; otherwise it would be drawn into the Sun. Mercury being the nearest planet to the Sun, is the swiftest, viz. thirty miles per second in its revolution; and so the ancients gave it its name after Mercury who, in their ignorant system of mythology, was called "The messenger of the gods." He revolves round the Sun in 88 days; while the Earth takes $365\frac{1}{4}$ days. Mercury, therefore, goes $4\frac{1}{4}$ times round the Sun for our Earth's once. His distance from the Sun is thirty six millions of miles; consequently he receives nine times as much light and heat as the Earth does. His apparent diameter at inferior conjunction i.e., when he comes between the Earth and the Sun, measures twelve seconds of arc, which corresponds to an actual diameter of 3000 miles.

MERCURY'S PHASES.

When Mercury is examined through a telescope, he is seen to pass through all the phases of the Moon. At greatest elongation, he appears like a half-Moon. Between superior conjunction and greatest elongation he is gibbous shaped; while between inferior conjunction and elongation he shows a thin, pretty crescent.

TRANSIT OF MERCURY.

Sometimes, in his journey round the Sun, he manages to get in a straight line between us and the Sun. The consequence is, that at such times, he is seen as a black spot crossing over the face of the solar disc.

Very little can be learned regarding the physical condition of Mercury, for our atmosphere interferes with our study of objects near the horizon where Mercury generally appears. His orbit is so near the Sun, that it is with the greatest difficulty and under the most unfavourable circumstances that any of his surface features can be detected.

About forty years ago Schiaparelli, a distinguished

Italian astronomer, was successful in the clear sky of Italy, in noticing several markings, by which he concluded that the planet rotates upon his axis in the same time that he revolves round the Sun, viz. 88 days, thus ever presenting the same side sun-wards. This conclusion was confirmed by the late Professor Lowell at Flagstaff Observatory, Arizona, who described the planet's surface as rough and mountainous, and his markings as long narrow stripes, some of which are straight; while others are curved. There is apparently no atmosphere. As the axis of the planet is perpendicular, there can be no seasons.

This long rotation theory may be regarded as an established fact. If the planet always presents the same side towards the Sun, there must be on the one hemisphere, eternal day, and on the other eternal night. Were our Sun to halt in his daily course through the heavens, and remain fixed overhead, the most disastrous effects would take place upon our planet. If there were no alternation of day and night, a noon-day Sun constantly pouring down rays vehemently year in year out, would increase the temperature on the side facing him, to 750° Fah. If the intensity of the rays of the tropical mid-summer Sun be multiplied by 9, we shall have some conception of the strength of those burning rays which fall upon the side of Mercury which continually faces the Sun. Conditions the reverse of these, would take place on the other side of the planet, viz., perpetual night and a temperature as low as that of interplanetary space. On the border of the two hemispheres, there would be a belt 47° wide, which would be alternately in sunshine and in darkness during the period of the planet's revolution round the Sun of 88 days.

SOLAR TIDAL FRICTION.

Mercury's long rotation period of 88 days is produced by solar tidal friction. As Mercury is much nearer to the Sun than the Earth, solar tidal friction is much more effective than it is on our planet. And so, just as

the tides raised by the Earth on the Moon, slowed down the Moon's rotation relative to the Earth; so the Sun's tides have stopped the rotation of Mercury relative to the Sun. Consequently, the planet turns the same face to the Sun; that is to say, one hemisphere has perpetual day; while the other has perpetual night.

Professor Lowell, in his "Evolution of Worlds" says, "Tidal force proves greatest on the planets nearest the Sun, and diminishes rapidly as we pass outward from him. If then the solar force has had time to produce its effects, it would be first in Mercury and then in Venus that it should be seen." From this it is obvious that the breaking of the rotation periods of these planets was a process continually operating through an immense period of time. To prove the truth of this theory, that tidal friction increases enormously with proximity, and is powerful enough to cause greater effects on Mercury and Venus than on the Earth, it may be of interest to know that the force produced by the Sun on Mercury is 6.6 times greater than that produced by the Sun on the Earth; while the force produced by the Sun on Venus is 2.5 times greater. I have obtained these results by employing the following principle; the maximum force tending to raise tides, is directly proportional to the mass of the disturbing body; and to the diameter of the disturbed body nearly, it is inversely proportional to the cube of the distance between them. The force in question is simply the difference in the gravitational pull at the centre and some other point of the planet.

$$\text{Tide-raising force } F = S\left\{\frac{1}{(R-r)^2} - \frac{1}{R^2}\right\} =$$

$$S\left\{\frac{R^2-(R-r)^2}{R^2\ (R^2-r)^2}\right\} = S\left\{\frac{2Rr-r^2}{R^2(R^2-2Rr+r^2)}\right\} =$$

$$S\left\{\frac{2Rr-r^2}{R^4-2R^3r+R^2r^2}\right\} = S\left\{\frac{2r-\frac{r^2}{R}}{R^3-2R^2r+Rr^2}\right\} = S\left\{\frac{2r}{R^3}\right\} \text{approx.}$$

Let S = mass of Sun.
R = distance of planet from Sun.
r = radius of planet.

For Mercury $F = S\left\{\frac{1}{(.387 - .0000326)^2} - \frac{1}{.387^2}\right\}$

$= S\left(\frac{1}{.3869674}\right)^2 - \left(\frac{1}{.387}\right)^2$

log .3869674 = $\bar{1}$.5876744

log „ sq$^{d.}$ = $\bar{1}$.1753488

$\log\left(\frac{1}{.3869674}\right)^2$ = 0.8246512 = log 6.678073

log .387 = $\bar{1}$.5877110

log „ sq$^{d.}$ = $\bar{1}$.1754220

$\log\left(\frac{1}{.387}\right)^2$ = 0.8245780 = log 6.676948

For Mercury $F = .001125S$ diff .001125

For Venus $F = S\left\{\frac{1}{(.7233 - .0000828)^2} - \frac{1}{.7233^2}\right\}$

$= S\left(\frac{1}{.7232172^2} - \frac{1}{.7233^2}\right)$

log .7232172 = $\bar{1}$.8592687

log „ sq$^{d.}$ = $\bar{1}$.7185374

$\log\left(\frac{1}{.7232172}\right)^2$ = 0.2814626 = log 1.911888

log .7233 = $\bar{1}$.8593185

log „ sq$^{d.}$ = $\bar{1}$.7186370

$\log\left(\frac{1}{.7233}\right)^2$ = 0.2813630 = log 1.911450

For Venus $F = .000438S$ diff. 0.000438

For the Earth $F = S\left\{\frac{1}{(1 - .0000851)^2} - 1\right\}$

$= S\left(\frac{1}{(.9999149)^2} - 1\right)$

log .9999149 = $\bar{1}$.9999630

log „ sq$^{d.}$ = $\bar{1}$.9999260

$\log\left(\frac{1}{.9999149}\right)^2$ = 0.0000740 = log $\bar{1}$.00017

$- 1.$

For the Earth F = ·00017 S diff. ·00017

	Mercury.		Venus.		Earth.
F	·001125 S		·000438 S		·00017 S
or as	112·5	:	43·8	:	17
(÷17)	6·6	:	2·5	:	1

It is obvious from these figures that the force is very much greater for Mercury and Venus than for the Earth. We thus see, that tidal friction tends to retard rotation, till it becomes equal to revolution. We have found that this has already happened in the case of the Moon, and has probably happened in the case of Mercury.

If we assume that the planet has a day nearly equal to our own in length, it is still doubtful whether it would be the abode of life. Its mass is so small, that it probably could not retain any of the lighter gases hydrogen and helium; and direct observation shows that its atmosphere, if any exists, must be very slight in amount. For example, when the planet crosses the sun, no ring of light is seen surrounding its disc as it enters the Sun's limb. In view of all these facts, we must conclude that Mercury is not a habitable globe.

VENUS.

Venus, the next planet, sometimes comes within 26,000,000 miles of our world. No other body ever comes so near the Earth, except the Moon, Eros, and comets. Venus sometimes appears two or three hours before sun-rise, and goes by the name of the "Morning Star." Sometimes she appears two or three hours after sun-set, and then she is called the "Evening Star."

PHASES.

Like Mercury, she passes through various phases, just as the Moon does. The more we see of the disc of Venus the further she is from us; while the thinner the crescent of Venus the nearer she is to us. The crescent of Venus is a beautiful object for observation, and may

be seen by a telescope of small power. She attains her greatest brightness 36 days before and after inferior conjunction about 38° from the Sun, when her form is similar to that of the Moon about five days old.

VENUS IN TRANSIT.

This planet, like Mercury, sometimes makes a transit across the face of the Sun; but much less frequently. The transits of Mercury happen about thirteen times in a century. Those of Venus take place in pairs, eight years between them, and then more than one hundred years elapse before there is another.

So rare are the transits of Venus in any particular place, that, from the year 1040 to the year 1283, A.D., none took place that could have been seen from Scotland. These transits have, of course, kept happening ever since the creation; but it is only within the last two or three hundred years that they have been noticed. It is to be feared that in former days men were more given to deeds of martial prowess than to looking for a dark spot moving across the face of the Sun. The last two transits of Venus occurred in December, 1874 and 1882 respectively. The planet will not repeat this performance till June 8th, 2004. The next after that will take place on June 6th, 2012. There will be no transits of Venus at all through the whole of this century. Thus, three or four generations of the human family pass away without having a chance of witnessing this rare phenomenon.

When a transit does happen to be observed, it is more of a suggestive than a grand phenomenon. To ordinary eyes, it is nothing but a black spot moving across the face of the Sun. The proportionate size of the two moving bodies, would bear the same relation to one another, as a pea to a rather small plate. The limb furthest from the Sun, when the planet is close to the Sun, has been seen illuminated as an effect of refraction. When she has fully entered on the Sun's disc, she is seen surrounded by a grey shade, indicating a dense atmosphere. By the spectroscope, this is found

to contain watery vapour, such as would fit the planet for animal and vegetable life like our own.

VENUS SMALLER THAN EARTH.

This planet is slightly smaller than our Earth in size, their surfaces being about 176 and 197 millions of square miles respectively; while the light and heat which she receives from the Sun, are nearly twice as great as that received by the Earth. Venus is probably in the same condition now, as our Earth was millions of years ago when our planet was covered with water and enveloped with a dense cloudy atmosphere full of water vapours. The dazzling whiteness reflected from the clouds of Venus, reaches the outside space, and gives the planet its remarkable brilliantly white lustre.

VENUS SIMILAR TO EARTH.

In size, mass, density and surface gravity, Venus is similar to the Earth; indeed she is often called the Earth's twin-planet. Many suppose that on that planet, conditions adapted for life correspond to our own. If she rotates on her axis in thirty-six or even forty-eight hours it is quite possible that she is inhabited; for the conditions which are essential to life—air, water in its liquid form, and fairly high temperature, are unquestionably realised. Arrhenius, Professor of Physics, in his recent book "Life in the Universe," in referring to Venus, calculates her average temperature to be 47° Cent. or 115° Fah., and her moisture about six times the average of that on the Earth; while at the Poles her temperature may probably be 10° Cent. or 50° Fah.

ROTATION PERIOD OF VENUS.

Until within the past twenty years, the rotation period was supposed to be nearly similar to that of the Earth. If so, she must have the same alternation of day and night. The markings seen, are said to be dim and vague. This proves Venus' gaseous envelope or atmosphere to be a very deep one, probably one hundred

miles. This envelope appears like a white mist overspreading the atmosphere. Professor Arrhenius, in his "Life in the Universe" says, regarding Venus' atmosphere, "When Venus is close to the Sun's disc, the dark body stands forth surrounded by a ring of light. The inside limit of the vapour shell which we observe, is the cloud wall, not the ground. These dense clouds very probably float, owing to the heat prevailing at a great height in the atmosphere; and as they rise to much greater heights than on Earth, we may assume that if there be ten times as much water in the air on Venus as there is in the air on Earth, the heavy rain-clouds there would rise to a height of six miles, and the light cirrus clouds should appear as high as $18\frac{1}{2}$ miles above the ground." From this, it will, of course, be seen that the hope of a frequent sight of the planet's surface is a futile one. In 1889 however, Schiaparelli came to the conclusion that Venus, like Mercury, always presents the same side towards the Sun, rotating once in the same time in which she makes a complete revolution round the Solar luminary.

Professor Lowell's more recent observations and markings, taken at Flagstaff, led him to believe that the planet has a slow rotation. He made a map of the markings. These are principally long, wide lines and circular spots. It is very probable, that the markings represented on them, are entirely an illusion. They do not in the least resemble drawings made elsewhere. If her day is the same length as her year, viz. 225 days; then Venus must necessarily be destitute of life. The day-light or sun-ward hemisphere will not be nearly so hot as that of Mercury, but it will be equally devoid of water and water-vapour; for this must, millions of years ago, have been swept by strong atmospheric currents to the frozen hemisphere of the planet, and left there in the form of snow and ice. The moisture would become frozen owing to the low temperature predominating there. By that means, it would be prevented, to a large extent, from returning. The longer this operation continued from period to period, one hemisphere

would ultimately be exhausted of its water and atmospheric covering, and the other hemisphere would be wrapped in a perpetual covering of ice.

There are however difficulties in the way of accepting this long rotation period of Venus. Lowell's theory, that the planet always presents the same face to the Sun, can only be held if the markings are real. It is by means of these that we can arrive at any conclusion as to its rotation. Even with the Sun, we have to rely on the sun-spots to prove the Sun's rotation. By their aid we know that the Sun rotates on his axis in $25\frac{1}{3}$ days at the Equator, but longer still in higher latitudes. It appears that the markings which we see, are of the nature of clouds. In that case, we cannot possibly ascertain the exact period of rotation. If the "Man in the Moon" were trying to ascertain the rotation period of the Earth, and got hold of a cloud instead of a mountain range, his conclusions would probably be unsatisfactory. Were we observing the Earth from Venus we would experience very great difficulty in seeing any of the geographical features of our planet. If Venus has an atmosphere similar to our own, we should expect an appearance as if there were a dense mist over the planet, and the features of the actual surface would be very difficult to make out.

We conclude therefore, that the supposed markings on the surface of Venus, appear to be optical rather than natural; and, in the absence of natural markings and similar planetary features it is absolutely impossible to measure the rotation.

Another objection to Lowell's theory of a long rotation period for Venus, is her size, mass and distance from the Sun. Had Venus been as small a planet as Mercury is, we should suppose that she had, after many millions of years, become like our Moon, a dry barren waste, with a rotation period equal to that of her revolution; but instead of that, she is very nearly equal to our Earth in size and mass. We cannot, therefore, suppose with Lowell, that Venus has a bare, desert like surface without water, vegetation, clouds, and polar

caps, when the investigations of all other observers confirm the presence of water, and when the spectroscopic researches made by the late Professor Vogel prove the existence of water or aqueous vapours in her atmosphere. If we admit the presence of either cloud or mist, then it is unlikely that the planet always turns the same side towards the Sun.

In trying to solve this difficulty the problem of tidal friction again comes into play. Taking into consideration the fact that the solar tidal friction of Venus is 2.5 times greater than that produced on the Earth, we conclude that her rotation period is necessarily a long one, but certainly much less than that of the planet's revolution of 225 days. If that be so, there must be a long night on the side away from the Sun, and probably a great deposit of ice and snow; but in time this region would return to the sun-light for an equally long period, and the ice would melt. According to investigations of Venus' spectrum by Belopolsky, the Russian astronomer, it has a period of rotation on its axis of about 29 hours. Professor Pickering, however, has recently found a period of 68 hours. Dr. C. G. Abbot, Director of the Smithsonian Astrophysical Observatory, is of the opinion that the planet has a short rotation period, and holds that she is "probably the most habitable spot, outside the earth, in the Solar System."

To sum up this difficult problem, we conclude that if Venus turns on her axis in a long period equal to her revolution round the Sun of 225 days, so far as the question of the possibility of the maintenance of life is concerned, we should put the planet much in the same category as the satellites of Jupiter, Saturn, Uranus and Neptune which rotate round their own planets and where the conditions preclude the possibility of vital existence. If, however, she turns on her axis in a period corresponding to that of the Earth or Mars, it is quite possible that there may be life, even intelligent life on her surface. When we consider the fact that Venus and the Earth are much the same as to mass and size,

and are the two planets in the whole solar system which most resemble each other, we would naturally expect that Venus has an atmosphere similar to our own in extent and density. Consequently, it is reasonable to suppose that the conditions of life on Venus, resemble those on the Earth far more closely than they do on Mars.

MARS.

Let us now turn our attention to Mars. This little planet revolves round the Sun in an orbit that is larger than, and outside of the Earth's orbit at a distance of 145,000,000 miles. The further a planet is from the Sun, the longer is its year. If the Earth and Mars started to go round the sun together, the Earth would overtake Mars at the rate of 28 mins. 42 secs. more per day. His velocity is 15 miles per second, while that of our Earth is $18\frac{1}{2}$ miles. Mars can never perform a transit across the Sun, owing to his being outside our Earth.

Mars was the name given by the Romans to the god of war, and this planet was named after him, owing to his sanguinary appearance. Though he is never a crescent or half-Moon when seen through the telescope, he sometimes has a gibbous phase, i.e., not quite round. Sometimes he is only 35,000,000 miles from us, while at other periods he is six times as far. If you represent the apparent size of Mars when he is near us, by a circle one inch in diameter, you would have to represent him by a circle less than one quarter of an inch in diameter to give an idea of his relative size when he is at his greatest distance. When the planet is even at his nearest approach to us, i.e., 35,000,000 miles, he is really at a very great distance away. A telescope that magnifies 1000 times, would show the planet to us as it would be seen by the naked eye if it were brought to a distance of 35,000 miles. This proves, that even the greatest telescopes cannot enable us to see much detail of surface on this little globe. If, for example, we had a bird's eye view of Europe from a height of

35,000 miles, i.e. ten times as far as from Aberdeen to New York, we could only see the broad outlines of the coast, and a great mountain mass like the Alps. The smallest object that we could possibly detect, would require to be as large as London. It may be a humiliation to our civic pride, but it would not be possible to see a point so small as the city of Aberdeen if it were on that planet.

TWO SATELLITES TO MARS.

Before we consider this planet at some length, it may be well to mention that it has two minute satellites. The outer one, Deimos, is 14,650 miles distant from Mars, and revolves round the planet in $6\frac{1}{4}$ hours. The inner moon, Phobos, is 5,850 miles from the centre of Mars. It revolves round the planet in $7\frac{1}{2}$ hours.

Phobos is a very wonderful satellite, because it rises in the west and sets in the east. It is the only satellite in our Solar System that revolves round its planet faster than that planet revolves upon its axis. While Mars is turning round once, its inner satellite is revolving three times round it. Mars rotates in a little more than 24 hours; while Phobos revolves round Mars in $7\frac{1}{2}$ hours. The consequence is, that the satellite sets rapidly in the east to the Martians, and rises rapidly in the west.

Notwithstanding the proximity of these satellites to Mars, their moon-light is not strong, on account of their smallness. The light of Phobos is only equivalent to $\frac{1}{69}$th part of that of our Moon; while the light that Deimos emits is $\frac{1}{1200}$th part of the illumination from our own satellite. During the most favourable opposition of Mars, the brightness of Phobos is only equal to a star of the 14th magnitude, while that of Deimos is of the 13th magnitude. Such faint magnitudes are of course telescopic. Owing to those satellites being so close to Mars, they must necessarily be small in size. Their diameters are 10 and 15 miles respectively. They have undoubtedly cooled down ages ago, and lost whatever air and water they ever possessed.

Let us now return to the consideration of the planet, and see what has been learned about it. Much more detail of surface may be seen on Mars than upon any other planet. We detect large regions of bluish-green which were commonly called seas and oceans, but which are now supposed to be districts where vegetation is plentiful. Other large tracts, covering more than half of the surface of Mars, are of a reddish-orange colour, and are supposed to be large deserts.

The polar areas are denoted by white patches, which increase and diminish with the seasons on Mars; and it is affirmed that these are snow-caps, owing to the fact that they are similar to the polar regions of snow and ice upon the Earth. During the Martian winter, these snow-caps form round the Pole of the planet which is turned away from the Sun, and increase in size. When the Sun begins to shine on them, they slowly diminish in area and almost vanish. These appearances suggest that Mars has an atmosphere containing aqueous vapour.

The day of Mars is only about 40 minutes longer than ours. The year there, is 687 of our days, or 669 of the Martian days. The axis of the planet is tilted out of perpendicular to the plane of its orbit, about 24 degs. 50 mins. Consequently, the seasons on Mars are practically similar to our own in their nature, the only difference being their length, which is almost double ours.

There are three difficulties in the way of asserting positively that Mars is inhabited by beings like ourselves: (1) the lack of heat from the Sun, (2) the lack of atmosphere, and (3) the lack of an abundant supply of water.

As Mars is 1.4 times further from the Sun than our planet is, it receives only one-half the amount of heat that we do. This fact would seem to prove, that in the absence of a dense covering of water-vapour to retain the heat, the temperature must be too low for ice to melt. The change of the polar-caps, however, contradicts this. The two polar regions, in turn, are exposed to the heat of the Sun continuously for nearly

twice as long as our polar regions. For a year the Sun shines without intermission on each Pole. During that period, there is no night, and there is no loss of heat by radiation ; or, if there is any, the amount is very much less than it would be in a region where there was the alternation of day and night. In consequence of this, the heat of the Poles must go on increasing to a certain extent. This undoubtedly explains the very rapid melting of the Polar-caps.

Professor Lowell, in favouring a temperature above zero, says in his "Evolution of Worlds," "Mars, owing to being cloudless and of a duller hue, turns out to have a computed mean temperature nearly equal to the Earth's, a deduction which the aspect of the planet corroborates. It thus enjoys a comparatively genial old age. On the whole, clear skies add more by what they let in, than they subtract by what they let out. If the Earth had no clouds at all, its mean temperature would be higher than it is to-day. Thus, as the planet ages, beneficent compensation is brought about, the Sun's heat increasing as its own gives out."

Professor Arrhenius, in supporting Lowell's view, says in his book, "Worlds in the Making," "This planet is endowed with an atmosphere of extreme transparency, and should therefore have a high temperature. Organic life may very probably thrive therefore on Mars."

This problem of temperature, is an exceedingly complex one. It has in fact, been considered as insoluble, and only to be estimated by a rough approximation from our own temperature. The mean temperature, while much lower than that on Earth, is not so low as to make life impossible. If that be so, we have on Mars, to a limited extent, the conditions essential to life—some water, a rarefied atmosphere, and a fair temperature.

The late Dr. Johnston Stoney, arguing in favour of a low temperature, suggested another kind of substance instead of snow, which might explain the appearance of the white-caps. He believed, that this white material

which increases in winter and diminishes in summer, may be carbon dioxide whose crystals are as white as those of snow, and whose temperature of crystallisation is much lower than that of water. It is difficult to see how the liquid encircling the melting ice-caps can be carbon-dioxide, for that gas does not become a liquid at pressures of less than five atmospheres, no matter what the temperature may be.

The second difficulty is the lack of atmosphere. In considering whether a planet is a suitable abode for human beings, the first essential thing is to ask if that planet has an atmosphere. As our globe is surrounded by an ample covering of air, the inference is, that beings who live on the surface of the Earth, must be adapted specially to the conditions which the atmosphere supplies. The atmosphere is so essential to life, that it is puzzling to think what kind of life could exist in a world without air. The atmosphere, to a great extent, lessens the fierceness of the Sun's rays which shine upon us. During the night, the atmospheric shell protects us from what would otherwise be the cold of space. The absence of a plentiful atmosphere, though perhaps not altogether rendering a planet unsuitable for life of some kind, must necessitate types of a different kind from those known to us here. In trying therefore to make an estimate of the probability of life in other worlds, it is absolutely necessary to consider if they possess an atmosphere.

A law which is quite general for all worlds is, that the larger the globe the more abundant the atmosphere by which the globe is encircled. The Sun e.g. is surrounded by a huge atmosphere full of gases and vapours; while the Moon, on the other hand, has practically no atmosphere. Now, in applying this law to Mars, we must notice that its mass and size occupy an intermediate position between that of the Earth and the Moon. It is much more adapted for retaining an atmosphere than the Moon is; while on the other hand, it is not so well fitted as our Earth is. Its mass is so much smaller than that of the Earth, that it has

advanced through its physical evolution at a more rapid rate than a larger planet would do, such as the Earth. The cooling of the interior must be far advanced in comparison with that of the Earth, on account of its being smaller and older than the Earth. The atmosphere would thus cool off in a smaller fraction of time than that required by our own planet. Notwithstanding this fact , it evidently retains a more copious atmosphere than the Moon; but it is much less dense than that of the Earth, probably one-fourth of the density of our own atmosphere. It is certainly more rare at the surface of the planet than our own is above our highest mountain tops. The force of gravity at the surface of Mars is less than two-fifths of gravity on the surface of the Earth. A weight on Mars would only fall six feet in the first second as against sixteen feet on the Earth. In consequence of this, barometic pressure falls $2\frac{1}{2}$ times slower with increasing height there than here.

It is therefore reasonable to expect, that a planet, having the size and mass of Mars, would be encompassed by an atmosphere. Our telescopic observations make this apparent. It is quite obvious that there is a thin covering of gaseous material surrounding Mars. On this assumption, those who favour the possibility of life on Mars hold that beings like ourselves might gradually become accustomed to a less dense atmosphere than ours.

The third difficulty, is the lack of large bodies of water. It is absolutely certain that there is a scarcity of water on Mars. Spectroscopic observations prove that there is little absorption by water vapour. Owing to the scarcity of water, no dense heavy clouds can form, such as we get in our lower atmosphere. The Martian clouds seldom assume a denser form than that of little cirrus clouds or haze.

There are other features in addition to the Polar caps, which appear to hint that water exists. In September 1877, when Mars was at his near approach to the Earth, wonderful discoveries were made by

Professor Schiaparelli. In the transparent sky and the suitable latitude of the locality of his Observatory, this distinguished Italian astronomer discovered that the regions usually described as continents on Mars, were crossed by a number of fine dark lines. He named them " canali," an Italian word for straits or channels, and may denote natural markings. Each of them must have been at least 60 miles in width; and in several they were thousands of miles long.

For many years, people cast doubts upon Schiaparelli's remarkable observations of the net-work of straight canals, many of which were discovered to be double; but they were confirmed by many observers, including Lowell, who published three books, entitled " Mars," " Mars and its Canals," " Mars as the abode of life." These works are based upon his own observations. His book on " Mars " includes an attractive map of drawings, showing portions of the planet, on which there are marked more than 400 canals; and of that large number 51 are double. He states that they vary in length, from a few hundred to a few thousand miles. He explains the irrigated regions on either side of the canals as lines of vegetation along artificial courses.

The canals are connected with the melting of the Polar-caps, and grow darker as the caps melt, just as if water were being conveyed along them. All this may be very easily explained, according to Lowell, by assuming that the canals have been constructed by a race of intelligent human beings, for the sole purpose of bringing water from the melting Polar-cap to the Equator.

Mars, owing to its small size, is relatively much older than the Earth, and is consequently scarce of water; and, if there are inhabitants, they would be compelled to utilise every drop which they could secure. Both the single and double canals of Mars are very straight, running on arcs of great circles from point to point on the globe. After several of them meet at a common point, there appears a round dark spot, to which Lowell gives the name "oasis." About 180 of these have now been

found, and the more prominent of these vary from 50 to 70 miles in diameter. The oases are supposed, by Lowell, to represent centres of population, where the inhabitants, driven from the desert-lands by scarcity of water, assemble round the ground artificially irrigated and fertilised.

Lowell concludes that as Mars is an older planet than the Earth, the inhabitants are probably in a higher state of civilisation. "What we see," says Lowell, "hints at the existence of beings who are in advance of, not behind us, in the journey of life." Thus, in Lowell's opinion, all the intricate Martian phenomena are explained on the supposition that Mars is inhabited by a race of intelligent beings.

Now let us investigate briefly the theories advanced by Lowell. 1. Observers, including Lowell himself, have noticed that some of the canals have been formed very suddenly; but at the next opposition of the planet, they could not be discovered. They apparently had vanished, or had been filled up by sand, perhaps as the result of earthquakes. This fact is a most convincing one, that the Martian canals are not magnificent products of engineering skill, for the construction of which we should require, on our Earth, hundreds of years and probably a denser population for their construction than Mars could support.

2. Lowell does not mention in what way this great work of engineering power is to be carried out. If the visible canals are caused by water flowing over land by artificial means in long sections from 50 to 60 miles in width, crossing the surface of the planet in straight lines in all directions, he does not tell us by what means the water is to be conveyed over this great region. He informs us that it commences at the Polar snows, and runs for thousands of miles to the Torrid zone, and even beyond it, stretching in every way over the planet; but he does not mention if the water lies in valleys, or on slopes and ridges. Our greatest magnifying telescopic power does not enable us to find out whether the planet's surface is level. Some of the large craters on

the moon, are the centres of systems of markings sending out their rays in all directions, crossing hills and valleys in straight lines for hundreds of miles. No one would imagine that their origin is the result of personal intelligence because they are straight and cast their rays from a common centre. Even though we suppose the canals to be real, we cannot infer from this that they are a certain proof of intelligent life existing on Mars.

If, however, Lowell's theory of the irrigation system of Mars be true, we cannot doubt that the Martians are more intelligent than we are; but on a sober consideration of the actual possibilities of the case, the conclusion seems inevitable, that this theory of a vast system of irrigation-works must be regarded as a flight of the imagination. It is foolish, in the extreme, to suppose that a meagre supply of water, by means of overflowing canals, could travel across the Equator into the opposite hemisphere.

3. The most natural explanation of the peculiar markings of the Martian surface is suggested by Professor W. H. Pickering that the canals are cracks in the volcanic crust, originated by internal forces. These have undoubtedly been caused by the heated interior of the planet gradually shrinking. As cooling advanced, every crack, formed near the surface, would increase in length, breadth and depth, and would incline to run on in straight lines, and to extend vertically downwards. In consequence of this, parts of long circles would necessarily be formed on the planet's surface. These cracks have, in all likelihood, come into existence by means of small craterlets, called by Lowell "oases," in a similar way to the white streaks on the moon which send out their rays from the huge craters as centres. On account of the rarity of the atmosphere, the small quantity of the water would run down the outsides of the craterlets and along the sides of the canals. By doing so, they would moisten the land and would thus be the means of advancing the growth of whatever forms of vegetation might prevail

on the planet, and thus render the canals and oases visible.

LIFE ON MARS.

Regarding the habitability of Mars, it is very probable that there are types of life of some kind or another on that planet. The two gases, hydrogen and carbon, are closely associated with life on our planet; and they also seem to be largely distributed throughout the universe. We must therefore conclude that they are present on Mars. At the same time, it is beyond our power to imagine what form the progress of evolution may have assumed. It is quite possible that air as thin as that on Mars, would sustain life in some form. It is probable that vegetable life of a comparatively high type exists on it; and that almost implies the presence of animal life of some sort; for we have already seen that there appears to be some evidence for the existence of water vapour in its atmosphere; and some though less at times, of the existence of water vapour on its surface in variable quantities; and some direct evidence of the presence of vegetation.

LECTURE IV.

Major Planets.

We come now to the consideration of the Asteroids, Major planets, comets, and to the discussion of the habitability of our stellar system.

ASTEROIDS.

At the commencement of the seventeenth century, Kepler observed that the distances of the planets from the Sun formed an orderly progression, with the exception of the gap between the orbits of Mars and Jupiter. He maintained that there was a planet revolving between these two. Little attention was given to this assertion until about 1772, when Professor Johann Daniel Titius of Wittenberg mentioned that the distances of the known planets coincided approximately with the series of numbers 0, 3, 6, 12, 24, 48, 96. When the number 4 is added to each of these, we obtain 4, 7, 10, 16, 28, 52, 100. Further, he emphasized the noticeable exception to the rule made by Kepler. This wide interval between Mars and Jupiter appeared all the more curious when, in 1781, Sir William Herschel found Uranus in approximately the same place where it was predicted that the next planet beyond Saturn should be according to the series of numbers. About that time Johann Bode noticed the wonderful way in which Uranus fulfilled predictions, and he published what is known as Bode's Law. Von Zach, a contemporary of Bode, held that there was in existence an undiscovered planet beyond Mars, so he made computations as regards its elements.

In the year 1800, two dozen astronomers formed

themselves into an association, and divided the sky into 24 zones, each astronomer observing carefully one of these zones. Shortly after they had commenced operations, Father Guiseppe Piazzi, a Sicilian astronomer of Palermo, discovered on January 1st, 1801, a star of the 7th magnitude in the constellation Taurus. He continued observing the object until he was quite certain that it was a small planet. At his request the planet was designated Ceres, after the tutelary goddess of Sicily, the island from whence it was discovered.

On March 28th, 1802, Dr. William Olbers of Bremen, discovered the second planet revolving around the Sun at nearly the same distance as the planet Ceres. This second planet, called Pallas, had an exceptionally large amount of deviation from the ecliptic, and also large eccentricity. He inferred from this, that there were still more of these planets. He was convinced that these two bodies were the remains of a large planet which had been broken to pieces in some unknown manner millions of years before.

In 1804, Harding discovered a third planet, Juno, and three years later Olbers discovered another, which he named Vesta, the brightest of all the Asteroids and faintly visible to the naked eye. In the years 1845 and 1847 respectively, the fifth and sixth were discovered by Hencke, which he called Astræa and Hebe. Since 1846, these small bodies have been discovered every year in ever increasing numbers, mostly by photography.

These planetoids were named Asteroids by Sir William Herschel, owing to their small dimensions and star-like appearance. It is a most difficult matter to measure them correctly, because of their diminutive size, the apparent diameter of the largest, being less than one second of arc. The actual diameters of the four largest are found to be 485, 304, 243 and 118 miles respectively. Most of them are much smaller, and probably their diameters on the average would not exceed twenty miles. Many estimates have been

made of the combined mass of the group, but it is computed that it is less than $\frac{1}{3000}$ part of that of the Earth.

Up to 1891 the work of finding a new planet was a laborious one. Many charts of the stars were constructed, and a portion of the sky, especially near the ecliptic, was compared regularly with these charts. In that year Professor Wolf introduced photography as a better means for finding these objects. The method he employed was to expose a plate for at least two hours. After being developed, the plate exhibited a round dot for each fixed star, and if perchance there appeared a planet within the field, a small elongated line would be seen, showing by its form that the planet had moved with respect to the fixed stars during the time of exposure. In this way, the finding of these bodies is more general, with the result that sometimes several have been discovered on one plate. Up to the present time the number exceeds 1000.

Regarding the origin of the Asteroids, a general opinion held is, that they possibly came into existence through the disruption of a solar ring similar to that of Saturn. Probably Jupiter prevented their aggregating into a large planet. The gravitational tidal action of that huge planet, owing to its proximity, would be sufficiently powerful to break up a solid body into thousands of fragments. This ring, ages ago, occupied the space within which the Asteroids revolve round the Sun.

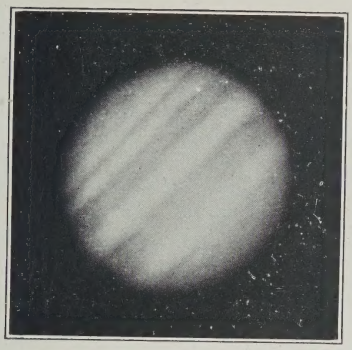
JUPITER.

Jupiter is the largest member of our Solar System. The ancients, in naming the planets after their heathen deities, called the most beautiful planet Venus, and the planet of most royal appearance Jupiter. The latter possesses a larger share of the attention of observers than the former. The brightness of Venus, owing to her nearness to the Sun, is of short duration, for she can never be seen in the sky throughout the whole

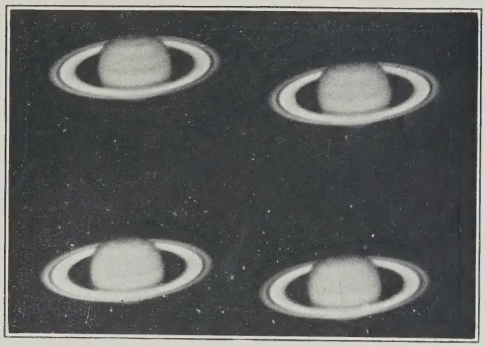
night as Jupiter may be. It is worth while mentioning, however, that when Venus is at her greatest brilliancy, she can be observed in the day-time in a clear sky notwithstanding the light of the Sun. She is then about 60 times as bright as Vega. When Jupiter is at his brightest, the most careless observer cannot fail to notice him immediately after sun-set. When he is nearest to us his apparent diameter is about $\frac{1}{40}$ of that of the Moon, and therefore a telescope with a magnifying power of 40, will show him with a disc equal to that of the full Moon. Even an opera-glass of the largest kind would be sufficient to show the planet with a slightly enlarged disc.

Jupiter had been studied with admiration for centuries, before it was discovered by Galileo, in 1610, that four Moons revolve round the planet. Since then, five others have been found. With a small telescope the four brightest satellites can be seen in a straight line at one period, all on one side of the planet, and, at another, part on one side and part on the other; while at other times one or more of the satellites are missing. The outermost of the four revolves in an ellipse, its period being seven days seventeen hours. The three others revolve in nearly circular orbits in periods of seven days four hours; three days thirteen and a half hours; and one day eighteen and a half hours respectively.

Professor Barnard has seen, with the great Lick telescope, white polar caps on the third and fourth satellites. He says "They are exactly like those of Mars. Both caps of the fourth satellite have been clearly distinguished, that at the north being sometimes exceptionally large, covering a surface equal to one-fourth or one-third of the diameter of the satellite." Professor Pickering observed that these satellites were of elliptical shape with belts parallel to the Equator. The fifth satellite, discovered in 1892 by Professor Barnard by means of the Lick telescope, revolves in a period of nearly twelve hours at an average distance of 70,000 miles from the surface, or 113,000 miles from



JUPITER. Exposure 10 secs.



SATURN.

Photographed by Professor Barnard.

NEPTUNE AND ITS SATELLITE.
Exposure 1 hour.
Photographed by Professor Barnard.

HALLEY'S COMET.
Photographed by Professor Curtis, Lick Observatory.

the centre of the planet. The satellites are frequently eclipsed by passing into the shadows cast by the planet, or occulted when he comes between them and the Earth.

The sixth and seventh satellites move round the planet directly in the same way as that of the motion of the large satellites, or of the planet's rotation and orbital motion. Their periods are 250 and 260 days, and their average distances from the planet 7,114,000 and 7,292,000 miles respectively. Both orbits are inclined about twenty-eight degrees to the plane of the planet's orbit, but in different directions, so that these planes make an angle of about thirty degrees with one another.

The eighth satellite was discovered on February 28th. 1908, by Mr. Melotte at Greenwich Observatory. It is of the 17th magnitude and revolves round the planet in a period of 739 days. It has a large eccentricity and a retrograde orbit. Its position and motion were obtained two months after discovery from the ephemeris by Dr. Crommelin. According to his computations, its distances from the planet at four successive times of closest approach, were 9,300,000, 8,400,000, 8,400.000 and 10,300,000 miles; while its successive maximum distances were 20,000,000, 21,000,000, 20,000,000 and 19,100,000 miles.

The ninth satellite was discovered photographically with the Crossley reflector at the Lick Observatory, on plates taken in July 1914. Had the satellite, like the eighth, not been near one of the other satellites and moving close to it, it is doubtful if it would have been discovered owing to its extreme faintness. Its average period is 745 days. Its eccentricity is a little less than that of the eighth satellite. Professor Nicholson at the Lick Observatory found in 1915, that when it was at its greatest distance from the planet, it was 17,600,000 miles from it; while its least distance in 1916 was 11,400,000 miles. In 1917, however, he found that it was 20,000,000 miles from Jupiter. Owing to these two satellites having highly eccentric orbits, they are

nearly twice as remote from the planet at their furthest as at their nearest, and the planes of their orbits are inclined about thirty-two degrees and twenty-four degrees to that of the planet's orbit, and about ten degrees to one another. The magnitude of the ninth satellite was found by Professor Harlow Shapley to be 18.3. Its actual diameter is only fifteen miles ; while its magnitude as seen from Jupiter, is 11.5. Its motion, like that of the eighth, is retrograde ; that is, they are revolving round the planet in the opposite direction to all the others. The average distances of these two satellites are approximately the same, viz., 14,600,000 and 15,000,000 miles respectively. The ninth and outermost satellite of Saturn, called Phoebe, which is only 150 miles in diameter, and the satellites of Uranus and Neptune have also retrograde motions.

JUPITER'S BELTS.

Several brownish streaks are seen across Jupiter's disc, known as belts. These vary from time to time both in their number and duration. They are probably caused by changes in the outer atmosphere of the planet. There is usually a bright zone lying along the Equator. Bright spots have been observed on these belts. The most remarkable one appeared in 1878, and has been known as the "Great Red Spot." It is 8,000 miles broad and 30,000 miles long. Some astronomers suppose that this spot is a great opening in the outer atmospheric envelope of Jupiter, through which are observed the dense red vapours of interior strata. Professor Lowell, in his "Evolution of Worlds," says "these cloud belts are vertical currents from the heated core and strung out in longitudinal procession by Jupiter's spin. They are self-raised condensations of what is vaporous below."

Jupiter is flattened at the Poles to a much greater extent than the Earth, owing to the great rapidity of his rotation. At the Equator his apparent diameter is 90,000 miles. This great world, which is 1,300 times larger than ours, rolls round on his axis once in every

ten hours. The Equator rotates five minutes faster than the temperate zones. His mean distance from the Sun is 483,000,000 miles; while he revolves round him in a period of twelve years in an orbit nearly circular and inclined at only 80 minutes to the ecliptic. This period of revolution works out an actual velocity for Jupiter of nine miles per second.

In regard to the physical condition of this giant world, the most careful study points to the fact that it must be at a temperature not far short of incandescence. It is probably, at present, in a semi-fluid condition, in fact quite a young world in an early stage of development, half-way between a solar and terrestrial globe; or as Lowell in his "Evolution of Worlds" says, "Jupiter is no solid, but a seething mass of heavy vapours boiling like a cauldron."

SATURN.

When the telescope is turned upon Saturn he is found to be the most wonderful and magnificent planet in the Solar System. Next to the Moon, he is the most beautiful object seen in the heavens. Before the telescope was invented, if he possessed any interest to observers more than another star, it was simply because, so far as was then known, he was the last planet in the system. He was, to the ancients, the most uninteresting of all the planets, and, were it not for the great telescopes of to-day, we would form the same idea. Formerly, the metals received names from the planets; so lead, the dullest and heaviest, is called after Saturn; while quicksilver is called after Mercury.

SATURN'S RINGS.

It was not until nearly fifty years after the invention of the telescope that the real nature of this wonderful planet Saturn became known. Huyghens was the first to explain it in 1656. He discovered that Saturn was surrounded by an immense, luminous ring. Galileo's telescope was not powerful enough to show this ring sufficiently, as it only magnified thirty times;

so he came to the conclusion that the planet was triple shaped. This ring is entirely separated from the body of the planet by a distance of 23,000 miles. Since the days of Huyghens, it has been found that what appeared to him as one ring, is composed of three broad, stately rings, two bright and one dark or dusky, called the crape ring.

In regard to this wonderful ring system, the late Professor Young said, "This sight is unlike anything else in all the universe. It is the most beautiful and the most interesting of all our telescopic objects."

Saturn is attended by ten Moons, the last one being problematical. Only three of them, however, are easy of observation. Several of them were discovered by photography, and are of the 15th magnitude. The largest of them is Titan, discovered by Huyghens when he was studying the planet with the object of finding out what these rings were. Titan is 3,000 miles in diameter, and about equal to Mercury in size—in fact a little world attending Saturn.

JUPITER'S AND SATURN'S TIDE-RAISING FORCE.

In my lecture on the Moon, I mentioned that the Moon's attraction towards the Sun, was considerably greater than that towards our Earth, and that if, when placed between the Sun and the Earth she were suddenly stopped in her orbit, she would depart from our Earth and fall into the Sun. In the case of the giant planets Jupiter and Saturn, however, it is worth while mentioning that they have a greater force of attraction on their satellites than the Sun has; consequently their moons would fall on the planets were they suddenly arrested in their motion. In working out this problem it is found:—

(1) That Jupiter's pull on Ganymede, the largest satellite, is 505 times that of the Sun.

(2) Ganymede's tidal force is 82.84 times that of the Sun.

(3) Saturn's pull on Titan is 377 times that of the Sun.

(4) Titan's tidal force on Saturn is 94.14 times that of the Sun.

The working is as follows.

Jupiter's tide-raising force

M = mass of Sun
J = mass of Jupiter
m = mass of Jupiter's Satellite
R = distance of Sun from Jupiter and from Satellite
r = distance of Satellite from Jupiter

To compare tide raising force of the Sun and Jupiter on a Satellite of Jupiter.

Sun's tide-raising force varies as $\frac{M}{R^3}$

Jupiter's tide-raising force varies as $\frac{J}{r^3}$

Ratio of Jupiter's tide-raising force to Sun's

$$\frac{J}{M} \cdot \frac{R^3}{r^3} = \frac{1}{1047}\left(\frac{R}{r}\right)^3$$

log R = log 5·2 = 10·7160
log r = 7·8542
diff = 2·8618

3 diff = $\log\left\{\frac{R}{r}\right\}^3$ = 8·5854

log 1047 3·0199

diff = $\log \frac{J}{M} \cdot \frac{R^3}{r^3}$ 5·5655

$\therefore \frac{\text{Jupiter's tide-raising force}}{\text{Sun's tide-raising force}}$ = 367,700

For Saturn's tide-raising force.

Ratio of Saturn's tide-raising force on one of his Satellites to Sun's tide-raising force is :

$$\frac{1}{3502}\left(\frac{R}{r}\right)^3$$

log R = 10·9795
log r = 7·9191
diff 3·0604
3 diff 9.1812
log 3502 3·5443
diff 5·6369
Ratio is $4{\cdot}335 \times 10^5$ or 433,500

Note :—

G = mass of Ganymede, J = mass of Jupiter: S = mass of Saturn.

If we substitute G for J, and T for S we get results of Satellite's tide-raising force compared with Sun supposing, as we have done, that the satellite and planet are equally distant from the Sun.

$$\left(\frac{R}{r}\right)^3 \frac{G}{M}.$$

Now this $= \left\{\frac{R}{r}\right\}^3 \frac{J}{M} \cdot \frac{G}{J} = 367{,}700 \times \frac{G}{J}$

$= 367{,}700 \times .00008844 = 32.84$

So $\left(\frac{R}{r}\right)^3 \cdot \frac{T}{M} = \left\{\frac{R}{r}\right\}^3 \cdot \frac{S}{M} \cdot \frac{T}{S} = 433{,}500 \times .000217 =$ 94

If gravitational pull be taken.

Jupiter.

log R − log r =	2·8618
2 diff	5·7236
log 1047	3·0199
diff	2·7037
Ratio is	$5.05 \times 10^2 = 505$

Saturn.

2 log R − 2 log r =	6·1208
log 3502	3·5443
diff	2·5765
Ratio is	$3.77 \times 10^2 = 377$

This planet is next in size to the giant planet Jupiter. Its equatorial diameter is 76,500 miles, while its polar diameter is about 70,000 miles. Its surface is 85 times greater, and its volume is 783 times larger than that of the Earth. Its surface gravity is about the same, while its mass is nearly 95 times that of the Earth. Its density is only $\frac{1}{8}$th that of ours. In other words, the weight of its material is but little more than that of cork. It is the lightest for size of all the planets. Consequently it must be only in the early stages of its formation and cannot possibly be the abode of life in any form. The surface which the telescope reveals, is the external portion of condensing vapours and gases.

Saturn revolves round the Sun in twenty-nine and a

half years, *i.e.*, our Earth makes twenty-nine and a half revolutions in the time that Saturn makes one. Its orbit is nine and a half times that of the Earth, and its speed in the orbit is only six miles per second. Consequently its motion among the stars is very slow. The length of a Saturnian day is ten and a quarter Earth hours, *i.e.*, it rotates on its axis in ten and a quarter hours. There is a difference however of twenty minutes between the equatorial and the temperate regions, that is, the latter require twenty minutes longer to make a complete rotation.

Saturn is nearly twice as far from the Sun as is Jupiter. Its mean distance from the Sun is nine and a half astronomical units, or 885 millions of miles. To use a simple illustration; a cannon ball moving 500 miles per hour, would take 200 years to reach Saturn from the Sun. This vast distance varies more than a hundred million miles owing to the eccentricity of its orbit. In its nearest approach to the Earth at opposition it is 750 million miles, while its furthest distance is 1030 millions. At this latter distance, light with a velocity of 186,330 miles per second, takes ninety minutes to travel from Saturn to the Earth; while, at its nearest position, it requires sixty-six minutes.

The plane in which the rings move round the planet is the plane of Saturn's equator, and the axis of this system is inclined twenty-seven degrees. The consequence is, that at the time of Saturn's equinox, the edge of the Ring System is turned towards us, and, because of its thinness, is not seen except through powerful telescopes. Midway between the equinoxes we see the rings open out again to a great width. These observations take place alternately every fifteen years. In 1915 the Rings were seen to be opened out to their full width. Since then, they have been gradually diminishing in width, and will apparently disappear as they did in 1907. Cassini was the first to discover that a dark stripe goes entirely round the ring. He also found that the ring was actually composed of two

concentric rings, the inner one being the broader and brighter of the two. This dark stripe separating the two rings is called "Cassini's division."

The external diameter of the outer ring is nearly 163,000 miles, and the width is 11,000 miles. The distance between it and the second ring is 2,000 miles. The external diameter of the inner ring is 110,000 miles, and the width 18,000 miles.

There is, in addition, another division called "Encke's division" which separates the outer ring into two.

In 1850, Professor Bond of Harvard Observatory, discovered what is called the "Crape ring." It extends to within 6,000 miles of the planet's equator. It is very faint compared with the other two—so faint indeed that it might be called dusky, and fades away until it is indistinct at its inner edge. The thickness of this ring system edgewise is about 100 miles. Professor W. H. Pickering mentions, that "while the outer rings are extremely thin, the crape ring has a very appreciable thickness of not far from 2000 miles."

NATURE OF THE RINGS.

The nature of these remarkable rings seems to be, that they are composed of great swarms of minute particles of matter, the various particles being situated so closely together to the extent of 100 miles deep, that they resemble a continuous stream of individual bodies moving in their own independent orbits round the planet.

As to their origin, Gore suggests that the formation of a ring is probably due to an abortive attempt at the formation of a satellite too close to the giant planet, while in Lowell's "Evolution of Worlds," it is stated that "What has happened to the Asteroids has likewise occurred in Saturn's rings. The disturber in this case has been, not Jupiter, but one or other of Saturn's own satellites."

A French astronomer named Roche, gave an explanation for Saturn's ring by showing that when a small body revolves near a planet, it is torn to

pieces by the tidal strains induced in it by the planet. The same explanation of the ring was also given independently by Clerk-Maxwell. On the Nebular Hypothesis a rotating globular nebula will throw off rings in its equatorial regions, because the centrifugal force overcomes the force of gravity, and these rings are supposed to condense into a planet or a satellite, though why the ring thus cast off should condense into a single body is not very clear. This would account for Saturn's rings if we suppose that the conditions for the ring condensing into a single body did not arise. That which looks to be the inner part of the ring, seems to be revolving faster than the outer part ; whereas of course a solid ring would revolve in the same time at all parts. This enormous planet, with its marvellous system of rings when studied with the telescope, fills the mind with feelings of awe and astonishment when we consider that we have here a giant planet nearly 800 times larger than the Earth, girdled with the most wonderful belt it is possible for the human mind to conceive.

URANUS.

Uranus is nineteen times further away from the Sun than we are. Its diameter is four times that of the Earth. It has a swift rotation period of ten and three quarter hours, and makes an entire revolution round the Sun in eighty-four years, travelling at the rate of $4\frac{1}{5}$ miles per second. It was discovered at Bath in 1781 by Sir William Herschel.

When a planet is seen through a telescope, its disc is always magnified. The higher the power, the larger it appears. Uranus was at first thought by Herschel to be a comet, but as its orbit was nearly circular and as its path was unlike that of a comet, it was soon found to be a planet. A certain fact discovered regarding the planet is, that the equatorial plane of Uranus coincides with the orbit plane of the satellites.

We know nothing whatever about its surface ; in fact it may have no proper surface. It is probably in a

similar physical condition to Jupiter and Saturn. Faint bands or belts are occasionally seen upon the disc of the planet similar to those of Jupiter and Saturn, which probably indicate a dense atmosphere. The light and heat which it receives from the Sun is about 350 times less than that received by us.

The planet is attended by four satellites, possibly more, which revolve in a plane nearly perpendicular to the ecliptic, in fact the planes of their orbits are inclined 97.8 degrees to the ecliptic.

Their periods are about two and a half days, four days, eight and three-quarter days, and thirteen and a half days respectively.

NEPTUNE.

The discovery of Neptune is one of the crowning triumphs in mathematical astronomy. The law of attraction has been impressed on all matter by the Creator. It is shown in the swelling of the tide as well as in the movements of the planets in their orbits.

After the discovery of Uranus, tables of his journey round the Sun were prepared, but it was found that he did not keep time. First he was too soon, then he was too late, now he was punctual, now too early again. These disagreements attracted attention; and the conclusion come to was that there must be a disturbing body somewhere. About the year 1845 two astronomers, hitherto unknown to fame, one Adams of Cambridge, the other Leverrier of Paris, independently entered on a laborious calculation about this disturbing body. The result was, a planet was discovered at last only one degree, i.e. two diameters of the Moon's disc, from the place in the sky they assigned to it by their calculations. This planet was Neptune.

Neptune is 2,800,000,000 miles from the Sun. Its diameter is nearly four times and its density one-fourth of that of the Earth. From this we infer that it is at a high temperature, and that, to a large degree, it is in a cloudy, vaporous condition. As compared with the density and size of Jupiter and Saturn, it is a globe

similar in appearance to those giant planets. The telescope detects faint belts crossing the Equator. It is probably quite a young world in the early stage of development, half way between a solar and terrestrial globe.

The rotation of this planet is a rapid one, probably less than twelve hours; while its revolution period is about 165 years. That means, its orbital velocity is about three and one-third miles per second. One satellite has been discovered as belonging to Neptune which, as already mentioned, moves backward in a plane inclined to the ecliptic at about thirty-five degrees, i.e. clock-wise from east to west. There is a change in the plane of the satellite's motion due to Neptune's equatorial protuberance.

COMETS.

Before considering the question of the habitability of these worlds we have been considering, let me direct your attention to comets and meteor streams.

Sir Isaac Newton maintained that comets are real members of our Solar System, and travel in paths of elongated ellipses. He held that they move outwards from the Sun at enormous distances, but ultimately return, owing to their elliptic movements. Laplace, on the other hand, maintained that comets belong to the stellar system, and that they travel through interstellar space. This idea was extensively held in the last century. About sixty years ago, however, there appeared evidence to the contrary, although the notion prevailed to such an extent that it was not until the commencement of this century that people in general entertained the opinion that comets are members of our Solar System. Astronomers, after careful consideration and diligent investigation, have found that the comets are moving along with our Solar System much in the same way as our planets are travelling with the Sun.

NUMBER OF COMETS.

Before the invention of the telescope, there were recorded 400 comets which were seen with the naked

eye. History informs us that many of these were of an enormous size, and approached closely both Sun and Earth. During the past 350 years, there have been found 450, the majority of which have been discovered with the telescope. The half of this number has been found within the last fifty years.

In addition to the comets which travel in orbits of very elongated ellipses into regions far removed from the Sun and planets, there are sixty-eight elliptic comets which are practically related to some one of the planets. About thirty-six of these are associated with the giant planet Jupiter. Some belong to Saturn and Uranus, while Neptune claims seven, one of which is Halley's long period comet.

As to the history of these periodic comets, a theory held among astronomers is, that they have been captured by the combined attraction of the Sun and one of the planets. A more probable theory, is that of Proctor, viz., that they have been erupted by the giant planets.

REMARKABLE COMETS.

It may be of interest to mention some of the most remarkable comets.

On the 5th October, 1858, a beautiful comet made its appearance. It was called Donati's, from the name of its discoverer. Its head was 250,000 miles in diameter, and the whole length of the comet itself was 45 million miles. It was calculated that, when that comet has reached the furthest part of its orbit from the Sun, it would be thirteen times further off than the furthest away planet, yet it would not be $\frac{1}{1000}$th. part of the distance of the nearest star. It returns to us only once in 2,000 years. If so, then, when last it visited the neighbourhood of the Sun, it was seen by people sunk in the idolatry of Druidism. With what awe and terror would they look on that comet, and how different would their emotions be from our feelings of admiration and reverence!

The comet of 1811 was visible through the autumn

of that year with the naked eye, and for sixteen months after with the telescope. Its head measured 1,200,000 miles in diameter, and its tail 100 million miles in length.

Another noted comet was that of 1843. It was so brilliant that it could be seen with the naked eye, close to the Sun, in broad daylight. In the southern parts of the world its tail was seen to reach over one quarter of the heavens.

HALLEY'S COMET.

One of the most interesting comets, not for size, but as being best known, is called Halley's. It was observed in the year 1682, and later shown by him to be identical with one seen in 1607, and also with that of 1531. Assuming their identity, Halley ventured to predict a return about 1758. This was a bold prediction for the days he lived in. No one had hitherto ventured to make such a conjecture. Knowing that he would die long before this, he expressed a hope, that if the comet should appear, posterity would remember it was foretold by an Englishman. As the time drew near, the excitement of scientific men grew to a great height. Eminent astronomers set to work to go through calculations about the comet again, and it duly reappeared within a month of the time forecasted by their calculations.

But when another period of seventy years had run its course, science had achieved still greater triumphs. Accordingly, in the year 1835 the comet reappeared within five days of its predicted time. At its next return it was visible in the autumn of 1909, and on April 19th, 1910, it passed its perihelion. At the time of greatest brightness the inner coma and parts about the nucleus varied much from night to night, and bright strong appendages were frequent. In the middle of May, streamers and envelopes issued from the head, while fainter material was observed outside of this. After passing the Sun in May, a new feature developed in the coma in the shape of a bright spherical

halo. It was sometimes so bright that it obscured many of the details of the inner coma. The portions of the tail near the head were observed to change frequently. In the beginning of May its tail was twenty-eight degrees long, and had a great fork commencing at eight degrees from the head. At twenty-four degrees from the head the extreme width was four degrees. A month later the tail measured twenty-seven degrees long and three degrees wide at the outer end. On June 7th there was seen a streamer of great intensity south of the principal tail, the velocity of the matter in the end of the streamer being calculated to be about fifty miles per second.

Regarding the length of the tail, in the middle of December 1909 it measured three minutes of arc, equal to 430,000 miles. In the end of January 1910 it was one degree in length, equal to 4,700,000 miles. On April 21st it was four degrees, equal to 9,200,000 miles. On April 30th it was fourteen degrees, equal to 19,000,000 miles. On May 5th it was 28 degrees, equal to 27,800,000 miles. The comet was last seen with the naked eye about the end of June. The brightness it produced at that time was greater than that of a star of the 6th magnitude. It was then 141 millions of miles from the Earth and 152 millions of miles from the Sun.

This comet is very interesting, from the fact that the returns of it have been traced back to the year 240 B.C. by two eminent astronomers, Drs. Cowell and Crommelin, Royal Observatory, Greenwich. Old writers call it a comet of monstrous size and appalling aspect, its tail appearing to reach down to the ground. In March 1066 a comet of large dimensions appeared in the heavens. Men thought it predicted the success of the Conquest of England. Researches made by Drs. Cowell and Crommelin have demonstrated the belief that the comet was Halley's. In 1456 it was spoken of as being of an unheard-of magnitude. It had a tail 60 degrees in length. People said that it indicated the success of Mahomed II who had taken Constan-

tinople and was spreading terror over the Christian world. The extraordinary brilliancy that is recorded, has induced astronomers to investigate the circumstances of its return, and on tracing the comet's motions back to 1456, it has been found that it was in such a position then as was most favourable to the exhibition of its magnitude and splendour; and so the results of astronomical calculation are seen to corroborate the records of history.

FEATURES OF THE COMET.

Comets have some distinguishing qualities, which must now be noted. The most prominent portion is a bright assemblage of misty, cloudy material, called the head, or coma. It is partly composed of solid matter, and alters in size considerably. The second feature of the comet is what is called the nucleus. This is a luminous circular spot, and is found near the centre of the coma. Its size changes enormously from a few miles to several thousand miles in diameter. The third feature is their tails. They are composed of fine gas and matter combined. These often grow to a great length. When a comet is seen at an immense distance from the Sun, the only parts visible are the coma and the nucleus; but as it approaches the Sun the tail stretches out to a vast extent. The comet of 1744 had a six-fold tail, and formed a glorious fan. Its length was nineteen million miles. This rare phenomenon is supposed to be connected with certain rapid changes which the gaseous substance of the comet undergoes on approaching the Sun. The great comet of 1577, seen with the naked eye before sunset, was divided into two streams. The length of the tail of Newton's Comet, 1680, was 100 million miles; while that of 1769 was forty million miles. The tail of the 1882 comet was 100 million miles in length; while that of 1843 was twice that length.

In receding from the Sun the tails become less, and, as a rule, they vanish before the coma and nucleus disappear from view. It has been noticed that some

of the comets which belong to Jupiter, do not possess tails. They do not seem to have material sufficient to enable them to produce these appendages. In Holmes' comet of 1892 for example, no tail could be seen through the telescope. Long exposure photographs of three hours length by Professor Barnard, recorded a very faint tail. It is interesting to note that the tails of comets point away from the Sun. They do so owing to light pressure caused by the Sun, which operates upon the gaseous matter discharged from the coma.

It is quite a common thing for comets to grow fainter with time. This is no doubt owing to a constant stream of matter which is cast out into the tail. It is natural that this should happen. There is abundant evidence to prove this from the observation of a number of those comets which return repeatedly to the Sun. Professor Campbell mentions that "almost all the comets belonging to Jupiter have a hazy, washed out appearance." Some of them do not develop tails, owing to the fact that the supply of matter which originally composed the tails has been completely used up. Some only develop short tails, while some short periodic comets have quite vanished.

COMETS' SPECTRA.

The spectra of comets are of various kinds. There are some whose spectrum is practically continuous, while there are others which show isolated bright lines. The spectrum of the nucleus appears to be a continuous one, except in the case of bright comets whose spectrum marks the usual absorption lines which are seen in the spectrum of the Sun. From this, it is apparent that the nucleus shines chiefly by reflected sun-light.

In most cases, portions of the coma and also of the tail show a spectrum of bright bands which, in past years, were called hydro-carbon bands. It has recently been found however, that this spectrum does not show a union of hydrogen and carbon, but a low pressure

carbon vapour band, or one of the compounds of carbon and oxygen, probably carbon monoxide. There is no doubt, that in the coma and tail of most comets, there exist lines and bands of cyanogen and carbon. It is generally agreed that carbon and nitrogen are present in comets, that oxygen very possibly exists; but it is very questionable if hydrogen is present. It has been noticed that comets which have passed within an approximate distance of the Sun have changed into a yellowish orange colour. The cause of this has been that the yellow light of sodium has increased to a great extent. This may very possibly be due to the high temperature of the material of the comets caused by the rays of the Sun.

METEOR-STREAMS.

A few words regarding meteor-streams are necessary here, because a close connection has been found to exist between comets and meteors or shooting stars. Astronomers are convinced that these are the remains of broken-up comets. As a rule, these minute projectiles are wholly consumed by their violent collision with our atmosphere; but now and again they are larger in bulk, pass through the atmosphere and strike the ground. These fallen meteors are aerolites; but for one aerolite that reaches the Earth, millions of meteors are destroyed. It has been estimated that about 20,000,000 of these shooting stars are burned up by the heat of friction with our atmosphere every twenty-four hours. Of course it is only those comets whose orbits pass very near that of the Earth which can give us meteors. We do not see the meteors until they come within our atmosphere.

The most famous of the meteor streams are the Perseids, named from the fact that their radiant point is situated in the constellation Perseus. They are generally seen in large numbers about the 10th August: hence they are called on the continent "The tears of St. Lawrence," owing to that day being sacred to that saint. The history of this shower can be traced

back to the year 811 A.D. It is usually believed that this meteoric shower is due to the disintegration of an ancient comet which moved in the same path.

A comet named Tuttle's, whose period of revolution is 131 years, and which appeared in 1862, belongs to this orbit. In the year 1866, Schiaparelli calculated the path of the Perseid meteors, and found that it was practically the same as that of the orbit of Tuttle's comet of 1862. It was found that they travelled on the same path. The one moved over the path a short distance before the other.

On November 12th and 13th there is also what is termed the Leonid stream of meteors, connected with Tempel's comet which appeared in 1866, and which belongs to the planet Uranus. The radiant point from which these meteors spring, is situated in the "Sickle" of Leo.

On November 12th 1799, and November 12th 1833, there were abundant meteor showers. Professors H. A. Newton of New Haven and J. C. Adams of Neptunian fame in 1864, studied attentively the history of meteor streams, and discovered that swarms of a similar kind had been witnessed at intervals of thirty-three years, as far back as 902, and they predicted that another would take place on November 13th and 14th 1866. When the time arrived, their prediction was fulfilled. Schiaparelli and Leverrier calculated the path of the swarm. Oppolzer also found that the orbit of the stream corresponded with that of Tempel's comet. There is no hesitation in concluding that these November meteor showers and Tempel's comet were moving in the same path. A return of this shower was confidently expected in November 1899, but it turned out to be a disappointment. It was found, immediately afterwards, that we failed to encounter the great stream owing to planetary perturbations, probably the attraction of Jupiter turning away the swarm from the Earth's path before the return of 1899.

Between the dates 23rd and 27th November, there

is another meteoric shower called Bielids, radiating from the constellation Andromeda. (It is also called the Andromedid shower.) There is a connection between it and the comet Biela, which is supposed to have lost all its gas and become dissipated.

About April 20th every year, there are also meteor showers which radiate from Lyra, and are named Lyrids. Weiss, a German astronomer, observed in 1867 that the path of the meteors radiating from this constellation is nearly the same as that of comet 1, 1861.

In May there is a meteoric display called the Aquarids, radiating from the constellation Aquarius, and it has been shown by Professors Alexander Herschel and Olivier, Dr. Crommelin and Denning, that it is connected with Halley's comet.

A statement has of late years been made by Professor Alexander Herschel, showing that there are seventy-six meteor streams whose paths correspond closely with those of seventy-six comets. In the year 1861, Kirkwood wrote "May not our periodic meteors be the debris of ancient but disintegrated comets, whose material has become distributed around their orbits." He registered eight comets, each of which had separated into different portions and had entirely vanished. From these facts we must conclude that the connection between comets and meteors is a very close one.

ZODIACAL LIGHT.

In connection with the subject of meteoric showers, it may be well to mention that the faint band of light which is observed to stretch well up in the sky towards the zenith from the western horizon during the fine spring evenings, and from the eastern horizon in the autumn mornings, is reflected sun-light caused by the swarms of minute meteoric bodies revolving round the Sun in elongated ellipses. It is called the Zodiacal light, because it lies along the ecliptic, i.e. it runs along the Zodiacal constellations.

HABITABILITY OF OUR SOLAR AND STELLAR SYSTEM.

And now we come to consider the question of the possibility of life in our solar and stellar system. We have seen that the Sun is too hot for sustaining life in any shape or form, and that it is an absolute impossibility for the Moon to support life owing to the total lack of water. We must also discard Mercury for the reason that its period of rotation on its axis is probably the same as its period of revolution round the Sun. It has also the drawback of lack of atmosphere; and we have seen what that means from the point of view of habitability. Jupiter, Saturn, Uranus and Neptune must also be put aside, for it is quite apparent they are not solids.

One strong argument which has been advanced against the habitability of these major planets, apart from these other considerations, is the diminution of the Sun's light and heat at such vast distances. At the distance of Neptune, for example, the Sun has an apparent diameter equal to that of Venus at inferior conjunction, and the light and heat received from it are only $\frac{1}{900}$th part of what the Earth is favoured with. This small fraction would not be adequate to sustain life like ours.

As to the Asteroids, we cannot suppose that any of them are warm enough or possess a sufficient atmosphere capable of sustaining life. They receive only ten per cent. of the light and heat that come to us. Their maximum temperature, under a zenith Sun, must be practically equal to that of interplanetary space. They must therefore be set aside as possible abodes of life.

In the whole Solar System then, we find only two planets, Venus and Mars, on which the physical conditions appear to be adapted to life not unlike our own; and even there, our physical conditions would have to be modified to a great extent, to enable us with our constitution to live on them.

In our survey of the different members of our Solar System, we have now seen that there are several conditions which must prevail before a planet can

sustain life. These are, the size and mass of the planet, its period of rotation on its axis, the inclination of its axis to the ecliptic, the shape of its orbit, the amount of available moisture, and the supply of light and heat which it receives from the Sun. Owing to these conditions, we can only conclude that it seems scarcely possible that there can be more than one or two planets belonging to any Solar System which can be suitable abodes for organic life.

Our own Solar System is not the only one that has been brought into existence. What shall we say about the stars, myriads of which are immensely larger than our Sun? Among the thousand millions of these glittering orbs there is no reason why we should not believe that there are inhabited worlds. We can assuredly affirm of each one of these luminous points which is visible to the naked eye, or which the telescope discloses, that it is a Sun—an intensely hot, glowing body shining by its own inherent light. We infer by analogy that there are many planets and satellites revolving round those Suns. We also infer by analogy, that among the millions of these invisible planets and satellites, there may be many like our own, and these may be inhabited by beings possibly not unlike ourselves. To suppose that our planet is the only one rushing through space which is inhabited, is so improbable, that we dare not make any such assumption. Although it is very probable that only a certain number of planets revolving round their parent sun are suitable habitations for life like our own, this does not shut out the likelihood that among millions of such globes, tens of thousands are so adapted. If this be so, then we must conclude from the analogies of nature, that however life had its origin upon our globe, there must necessarily have been a progressive improvement in the development of living forms, which have advanced from one stage to another in the scale of being. Protoplasm is the physical basis of life, and there can be no protoplasm where water does not exist in a liquid form for considerable periods of time. The

probability that there can be, within the Solar System, any body capable of exhibiting the phenomenon of life which is at the same time unfitted for the retention of water in liquid form, seems to be a small one. If that view be correct, it would seem to rule out the possibility of the existence of any but the lowest forms of vegetable life, such as bacteria which are found in the atmosphere of the Antarctic continent, on any of the planets and satellites of the Solar System, except Earth, Venus, and Mars.

One of the great ends of nature is the production of life; but it can only exist within the compass of a moderate temperature at which water remains in a liquid condition, and in places where the rays of the Sun can reach. At a certain period of our Earth's history our globe was a mass of boiling matter, and consequently could not be a dwelling-place for life of any description, any more than the Sun could be; but, as soon as the conditions were favourable, life commenced with the simplest forms and developed into its present countless variations by an evolution necessitating many millions of years.

No life could have come into existence of itself. For the origination of life in any form, the living germ is absolutely essential. How then can we account for the first germ? Where did it come from? The late Sir William Thomson, otherwise Lord Kelvin, made the suggestion that life may have come to our globe by a meteor entering our atmosphere from space. Instead of this solving the problem, it makes it more intricate, for it raises the question, in what manner life originated on the meteor; and if we admit this, another difficulty presents itself, why was it not annihilated by the heat produced as the meteor flashed through the atmosphere?

The most prevalent and feasible opinion regarding the commencement of life which science has never been able to disprove is, that it originated through a specific act of creative power. If that be so, we cannot imagine that that work was limited to one of the thousands of millions of planets rushing through space.

There is therefore every probability that other worlds are occupied by beings not only endowed with animal life but also with reason.

We may assume that life on those distant planets may begin whenever the conditions are favourable, though the forms which it takes may be quite different from those known to us on this planet. But in our supposition of the existence of life in other worlds, we must confine ourselves to forms which are subject to the same conditions under which life is possible here. If some people urge that various forms of life can exist on planets where the temperature is at boiling point, or on frozen worlds where the temperature is 350 degrees below zero Fah., then this is a matter on which we cannot speak. It is beyond all human experience, and conjecture concerning such organic life is futile.

We have learned from the spectroscope that chemical elements known in our laboratories abound throughout the stellar universe. We may therefore infer by analogy, that the elements necessary for the existence of vegetable and animal life on Earth, are found on other worlds.

In closing, I should like to impress upon you one thought that has constantly recurred to my mind, as I have no doubt it has to yours while we have been pondering the great universe of matter, law, and energy disclosed to us by the eye and the telescope. It is this, that after all, the human mind and soul is greater and more marvellous, loftier, and worthier than even the stars in the universe. We are "made in the image of God," an expression, the fulness of whose meaning we shall better understand hereafter. We share His nature and His eternal life. When we measure our weakness and littleness against the immensities of the heavens, it is true still that "God is mindful of man and visits the son of man in whom is the breath of the Most High." As the poet has expressed it:

> "The thoughts of human hearts outvie
> The movements of a million suns,
> The rush of systems infinite through space."

LECTURE V.

The Stars.

The subject I have chosen for the remaining six lectures is a very wide one, namely, the stellar universe. To-day I shall mention some of the relevant facts disclosed to us in the great field of astronomical science.

I. The fixed stars and their distances.

In primitive times the stars were supposed to be fixed, because to the naked eye their positions do not appear to alter as those of the planets do. The well known stars in the constellations Orion and Taurus which appear in winter, and those in Leo and Virgo which appear in spring, have apparently the same relative positions that they had 1900 years ago when the "Star of Bethlehem" attracted the attention of the Magi and led them to the infant Christ. These stars were accordingly to them, and to those who lived in the first century of our Lord, just sparkling points of light firmly fixed to the surface of the sky, their daily rotation causing them to move in a body round the stationary Earth, from whence they could be observed to rise and set.

People held this notion until Halley in 1718, disclosed the fact that some of the brightest stars, such as Sirius, Procyon, Arcturus and Aldebaran had visibly altered their relative positions among the stars nearest to them. But before that year, it was not positively certain that the stars had motions of their own. People then had not the least conception regarding the dimensions and remoteness of these heavenly

bodies, any more than as to their motion, so they could only theorise.

Bradley, who was the first to discover the aberration of light—he published his theory in 1729—showed, not only that the Sun and planets were merely a very small part of the steller universe, but also that the distance of even our nearest stellar neighbours, must be thousands of times the Earth's distance from the Sun. He also demonstrated the fact that the stars must be very remote because of their intrinsic brightness, for, were it not for their remarkable luminosity, it would be absolutely impossible for us to see them even by the aid of the telescope, since the apparent brightness diminishes quickly in proportion as the distance increases. Hence, the conclusion arrived at was, that stars are necessarily of the same degree of inherent light-giving power as our own Sun and of similar dimensions.

Although the distinctions between stars are undoubtedly vast, both as to distance and luminosity, there is no denying the fact that they are all suns, and that our own Sun may be regarded as a very ordinary one. The motion of the stars was not absolutely confirmed until the commencement of the eighteenth century, and it was 100 years or more after Bradley's observations, that accurate measurements of the distance of a star were first acquired. The precise measurements of stellar motions and distances which began to be practised less than a century ago, demand very great care, and can only be obtained by means of most accurate instruments in the hands of skilled observers.

The whole subject of stellar distance is a most perplexing one, owing to the vastness of the quantities involved. A unit of even a billion miles is a comparatively short one. Usually the surveyor finds 1000 yards quite long enough for ascertaining the distances required, and, occasionally he will measure off ten miles for a base line. The problem however, which the astronomer has to solve, is a much more difficult

one, because an immensely longer base line is necessary for stellar distances. Even the diameter of the Earth's orbit is far too small to use as a base line in measuring such distances. But the diameter of the Earth's annual orbit is 186,000,000 miles; and this diameter subtends, at the nearest stars, an angle which can be fairly well measured. Now the Earth, by its yearly motion, passes in six months from one end to the other of a diameter of its orbit; and so, by observing the same star at an interval of six months, its displacement, due to the annual parallax, can be measured. If the position of a star in the heavens be found in June for example, and then again in December after a period of six months, the Earth will, during that time, have moved us round to the other side of the Sun, *i.e.*, 186,000,000 miles from the position the Earth occupied in June. Then, if a small displacement is found in the position of a star between the two observations, by solving a simple triangle, given the length of the base and the value of the two angles at the base, the distance of the star can be ascertained. Were we at the star, and could see the Earth, the parallax of the star would be one half the small angle subtended by the diameter of the Earth's orbit about the Sun when she moved from one side of her orbit to the other.

To ascertain the very minute change in the position of a star, is one of the most intricate problems in mathematical astronomy. Stars are so remote, that this angle, called the parallax, is extremely small. The diameter of a sixpence at a distance of two miles from the observer, would be one second of arc. A tennis ball seen at a distance of eight miles, would give the same result. If it were possible for us to see a man 250 miles distant from us, his height would represent only one second. A thin thread placed in the field of view of a telescope, would be sufficient to hide the portion of the heavenly sphere where the apparent movement of the stars under observation had taken place.

The parallax of one second of arc means that the

star is 206,265 times further away than we are from the Sun, the Sun's distance being one-half of the base line, or about 93,000,000 miles. If then the parallax of a star be less than one second of arc, that star must be further away than 206,265 times 93,000,000 miles. This is found to be the case with every star in the heavens. Alpha Centauri, the nearest star to our Solar System, a bright 1st magnitude star in the southern sky, gives the greatest parallax of any. But even this star's parallax only subtends three quarters of a second of arc. This means, that Alpha Centauri is twenty-five billions of miles distant from us, or 275,000 times the Sun's distance from the Earth. It takes light four and one-quarter years to reach us from this star. So it is quite correct to express the distance of Alpha Centauri in light years, *i.e.*, the distance that light, travelling at the rate of 186,330 miles per second, would cover in the course of a year.

The actual distance from the Earth to the Sun, Moon and planets, is fairly accurately known; but when attempts are made to determine the distance of the stars, no such degree of accuracy can be claimed. Some of the faintest stars are undoubtedly 5,000 light years distant from us. That means, if their light were blotted out to-day, the inhabitants of this Earth would not be aware of the fact for 5,000 years hence.

Before mentioning various methods employed for finding a star's parallax, it may be well to state briefly several movements due to precession, nutation, aberration, and the star's own proper motion. The Earth is carried round the Sun while rotating on its own axis, and meanwhile Sun, Earth, and planets are moving together through space, as first determined by Sir William Herschel, at the rate of about twelve and a half miles per second. The direction of this motion is about seven degrees south-west of the bright star Vega, whose distance from us is thirty-five light years. Researches do not agree absolutely, but nearly, on the position. The effect on the positions of the stars is to cause those in front to apparently open out, those

behind to close up; while in other regions of the sky they drift backwards. The apparent displacement of a star, due to the solar motion in space, is called the parallactic motion. And by means of this displacement the distance of a group of stars can be found, just as the distance of an individual star is found from its annual parallax due to the motion of the Earth round the Sun.

Again, although light has an exceedingly great velocity, yet this velocity is not so great but that it can be combined with the velocity of an observer, carried on the Earth round the Sun at the rate of about eighteen and a half miles a second. Thus is caused an apparent displacement of a star when observed at any moment, which is called aberration. The star moves in an apparent orbit generally elliptical, with the greater axis forty-one seconds long, and parallel to the ecliptic a quarter of a revolution ahead of the Earth. Not only do we view the stars from a moving platform, but also from one that is swaying and wobbling. This wobbling motion causes the Pole of the Earth to describe a circle in the skies about the fixed Pole of the ecliptic, in about 25,800 years. At present the Pole of the Earth points to a spot in the sky very near the bright star in the tail of the Little Bear. At the time when Hipparchus constructed his star catalogue it was twelve degrees further removed, and in about 12,000 years hence the brilliant luminary Vega will serve as the Pole star. This is the condition which involves that the Sun appears to cross the Equator, and to go north a little earlier every year. The equinox moves westward on the ecliptic, and advances to meet the Sun as it returns to make its annual path across the equator. This phenomenon, which is called the Precession of the Equinoxes, is due to the attraction of the Sun and of the Moon upon the ring of matter at the Earth's equator, due to its departure from a truly spherical shape.

But the Sun and the Moon are not always pulling at the Earth's excrescence in the same way, and they

change their positions with regard to the Earth's equator in indefinite periods. And so the circle traced by the Pole among the stars, is in the form of a wavy curve, the phenomenon known as Nutation or nodding, with 1,400 waves in the circumference completed in 25,800 years. Hence, the positions of the stars in right ascension and in declination are both affected.

In taking count therefore, of star movements, they must be corrected for all these displacements, which are in reality due to the motion of the Earth. What remains over and above, is the stars inherent proper motion.

But the annual motion of the Earth about the Sun, causes a small change in the direction in which a star is seen, an apparent displacement due to the real motion of the observer. The star seemingly traces out a very small ellipse in the sky. This periodic motion is superposed upon the uniform proper motion of the star. It must be disentangled from it. The parallactic displacement is generally much less in amount than the proper motion of the star. The effect is virtually to transfer the elliptic motion of the Earth round the Sun to the star, as if the Earth remained at rest, and the star described the elliptic orbit on a vastly reduced scale, and six months ahead of the Earth. The measurement of the major axis of this minute ellipse, evidently gives the angle subtended by the major axis of the Earth's orbit round the Earth, when viewed at the great distance of the fixed stars. This enables their distances to be gauged.

There are several different methods employed for the purpose of ascertaining the small change in the position of a star as the Earth moves from one side of its orbit to the other, and thus of obtaining the star's parallax. The first three processes to be employed, involved the use of the transit circle, the micrometer or heliometer, and photography.

The first consisted simply in observing with that instrument, the apparent right ascension and declination of a star at various times of the year. From the slight

variations in these coordinates it was possible to find the parallaxes of the nearest stars.

Another and better method of finding the parallax of a star is that of measuring with a micrometer or heliometer, at periods of six months, the angular distance between two stars situated optically very near to each other, one of which has a large proper motion; while the other has little or none. Many stars are observed to travel an appreciably short distance every year; while others travel so slowly that their motion can only be discovered after a period of fifty or a hundred years.

The ordinary process employed now-a-days to determine the parallax of a star, is photography. This method was first adopted by the late Professor Pritchard of the Oxford University with a first class reflector of thirteen inch aperture. If two photographs are taken of the same part of the heavens at an interval of six months, the displacement made by the star which is under observation can be ascertained by means of a measuring microscope. A photographic plate is exposed to the section of the sky in which the star is situated whose parallax is sought. The undeveloped plate containing the images of this particular star and all the others in its vicinity, is then laid aside for six months and protected from the light. At the end of that period the plate is again exposed, and another photograph taken of the same section. Of course the plate is slightly shifted to prevent the two images of each star from falling on the top of one another. After this is developed, all the stars are seen in their exact positions relative to the positions they occupied six months previously; and the variation is then measured by means of the microscope. By comparing the two photographs taken at this interval, we can determine the parallax of the particular star.

Notwithstanding all the efforts made to solve this problem, the distances of only about 900 stars have been found, and of that number, only one half are precisely known. From these direct methods the

distances of only the nearest stars have been determined. Still, when we compare this number with that of forty years ago, we cannot but be impressed with the progress that has been made in our knowledge of stellar parallaxes. Sir Frank Dyson has mentioned that in 1880 we had values for the parallaxes of twenty stars, in 1900 for about sixty, in 1915 for 350. In 1915 he wrote "The question may be asked, how near must a star be to us for its distance to be measurable? I think we may say ten million times the Sun's distance. This corresponds to the small angle 0″.02 for the parallax." This statement still holds good to-day.

SPECTROSCOPIC METHOD OF DETERMINING THE DISTANCES OF THE STARS.

We must distinguish between the apparent magnitude of a star, which depends on the intensity of the illumination it sends to the retina of the eye, and its real luminosity or illuminating power, which is something intrinsic. A very bright star might, on account of its great distance, appear to be very faint, though it is true to say, on the average, that the faintest stars are among the most distant. The apparent magnitudes of the stars are well known, even of the faintest stars, owing to extensive observations both visual and photographical. Each magnitude or class of stars in order of brightness, denotes an apparent lustre which is nearly 2.512 times as bright as the succeeding magnitude.

I may point out that 2.512 is the fifth root of 100, so that five magnitudes mean one hundredfold diminution of light, or tenfold increase in distance.

Again, it is evident that should we wish to compare, not the apparent brightness, but the intrinsic luminosity of stars, we must view them equivalently at the same distance from the eye. Astronomers have agreed that the standard distance should be a distance from the Sun corresponding to a parallax of a tenth of a second of arc, or thirty-three light years. The absolute

magnitude of a star is defined to be its apparent magnitude when viewed at the unit of distance. The word absolute in this connection is somewhat of a misnomer. What we are really comparing is the relative brightness of the stars at a standard distance from the Sun. The Sun himself has an apparent magnitude of −26.5, but when placed at the standard distance would have an absolute magnitude of 5.

A simple formula connects the absolute magnitude of a star with its apparent magnitude and with its parallax. The apparent magnitude of all the stars is well known. If the absolute magnitude can be found, then the parallax or distance of the star can be calculated. It is here that the spectroscope comes to the aid of astronomer. It is known that some radiations of the chemical elements as observed with the spectroscope, betoken a low temperature and corresponding feeble luminosity, and others a high temperature and corresponding great luminosity. Their degree of strength in a star's spectrum, is an indication of its physical condition as to luminosity. They serve as a delicate pyrometer to gauge a star's relative temperature, and hence its absolute magnitude. For instance, a radiation of calcium at wave-length 4455 is greatly strengthened in the star 61 Cygni, and is weakened in the star Alpha Tauri. The opposite conditions obtain with regard to a radiation of strontium at wave-length 4216. Now, laboratory and solar researches have shown that the radiation of calcium 4455 is one that increases in strength with reduction of temperature. But the strontium radiation 4216 is one that is indicative of high temperature, for it is found in the electric spark spectrum of the element, and in the hotter layers of the Sun. We should therefore conclude in a general manner, that Alpha Tauri is hotter than 61 Cygni and has a higher absolute magnitude. But how much higher?

The discovery was made by Dr. Adams of the Mount Wilson Observatory, and it is a discovery of prime importance, that the absolute magnitudes of

the stars can be graded according to the strengths of such radiations in their spectra. A set of iron lines of constant intensity, form the fiducial points or bases of reference for the determination of the intensities of those radiations, which vary with absolute magnitude. The intensity of such radiations bears a numerical relationship to the absolute magnitude of the stars in which they occur. Curves can be plotted expressing this relationship graphically, and by their aid, given the strength of the spectral radiations, the absolute magnitudes can be determined. But the apparent magnitudes are already known, hence, knowing the absolute and the apparent magnitude of a star, its parallax is found.

The accuracy of this method of deriving parallaxes from the intensities of spectral radiations, depends upon a knowledge of the parallaxes of those stars which were originally used for the determination of the relationship between absolute magnitude and intensity of radiation. Some known parallaxes of stars were required as the foundation stones of the investigation. About 1680 stars have now been investigated by this method at Mount Wilson including nearly all the stars the parallaxes of which had been previously determined by trigonometrical methods. Hardly one serious contradiction has been found between the spectroscopic and the trigonometrical parallax. This is a splendid testimony to the accuracy of the method. It is evidently capable of extension to stars, however remote, of which the spectrum can be obtained.

RADIAL VELOCITIES OF THE STARS.

By means of the spectroscope we can also ascertain the radial velocities of the stars. Radial velocity is the velocity with which the stars move in the line of sight towards us or from us. This motion is found by measuring the displacement of the spectral lines due to the approach or recession of the source of light. When a star is approaching us, the lines are slightly shifted towards the blue end of the spectrum; when

however it is receding from us the lines are shifted towards the red end. From the amount of the observed displacement of the lines measured in the field of the spectroscope, the velocity in miles per second at which the star is travelling in the line of sight either away from us or towards us, can be calculated.

Professor Campbell, at the Lick Observatory, has been able, by long and careful observation, to find the radial velocity of more than 1,500 stars; while Professor J. S. Plaskett, Director of the Dominion Astrophysical Observatory, has recently published the results of measures of spectrograms for the radial velocity of 594 stars, obtained with the 72 inch reflector. It is interesting to mention, that out of this number, one of the stars whose magnitude is 5.7 and whose spectral type is K2, has a swift radial velocity of 97 kilometres per second.

STARS WITH GREAT VELOCITY.

There are more than a dozen stars known, which are rushing through space with high velocities. Some of the most notable are 1830 Groombridge which moves 7″ every year; 61 Cygni 5″.14: Mu Cassiopeiae 3″.75; Alpha Centauri 3″.68; Arcturus 2″.28. The swiftest of all stars known are the faint star called the "Galloping star" in the southern constellation Pictor, which has an annual motion of 8″.7; and Professor Barnard's "Runaway star" in Ophiuchus.

The discovery of the latter star by Barnard is a very interesting one. After photographs of the sky had been taken on various occasions, comparisons of these photographs were made, and it was found that one of the stars which appeared on one of the photographic plates was not visible on the other. Some time after, a photograph was made of the same part of the heavens, and, on examining the plate, it was found that a second star had made its appearance a short distance from the one that had been missing, in a position where no star was visible on the earlier plate. On examining a third

plate made at an intermediate date, no star was found in either of these positions: but a star similar in brightness to the others, was visible on a line joining the earlier and later positions and half-way between them. There was no doubt then that there was one star only, which was changing its position towards the north every year so rapidly each time it was photographed that it did not appear in the same position on each of the three plates. From the time of the first photograph in 1894, to the time of discovery in 1916, it had a northward motion of four minutes of arc, or $10''.25$ annually. At this enormous velocity the star moves one degree in the heavens every 350 years. The spectroscopic results of Professors Adams, Campbell and Slipher indicate that it is approaching our Solar System with an actual speed of seventy miles per second. Its parallax has been recently measured and is found to be $0''.55$. This corresponds to an actual distance of six light years. From this, it follows that its speed at right angles to the line of sight, equals about ninety kilometres per second. This high velocity would carry it from the Sun to the planet Uranus in one year. In an article written by Dr. Crommelin in the Monthly Notices of the R. A. S. in 1916 he mentions that this star was probably observed by Lamont at Munich on July 24th 1842, and was numbered 15,040 in Munich.

Crommelin estimates its visual magnitude at nine, and classes it among the Mb spectral type and in the last stages of decline.

PHYSICAL NATURE AND CONSTITUTION OF THE STARS.

We must now devote a short time to the consideration of the physical nature and constitution of the stars,

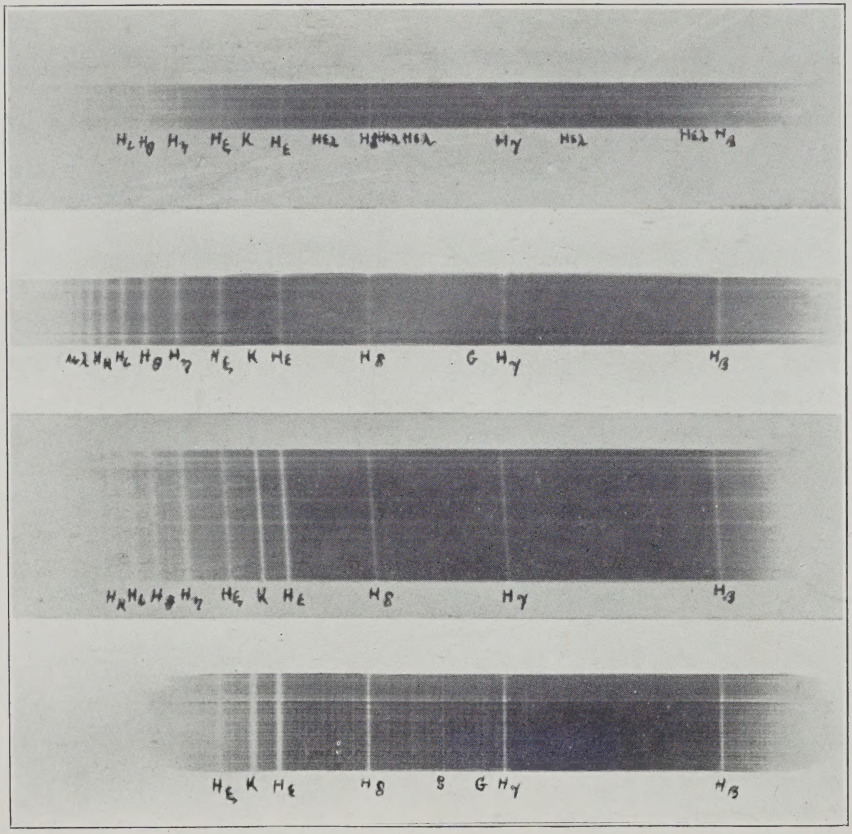
The spectroscope not only informs us whether the stars are approaching or receding from our System, but it also furnishes us with precise knowledge as to their constitution and physical condition. This wonderful instrument is unquestionably the most powerful agent in unfolding the mysteries of the universe that has ever

been discovered, for if an ample supply of light be obtainable, we can study the most distant objects as well as the nearest; and, by analysing the inherent character of the light, we can discover not only their actual speed, but also their chemical constitution and the physical condition of their outer radiating surfaces.

When the stars are classed according to the elements indicated by their spectra, it is found that they fall into a small number of types characterised by their peculiar spectrum. They appear to the naked eye under various colours as white, bluish white, yellow, purple and red. When, however, the spectroscope is turned upon them, their spectra are found to be varied and many. Father Secchi of Rome, in 1866 and 1867, analysed with the spectroscope, more than 4,000 stars down to the 6th magnitude, and divided them into four different types.

Those belonging to Type 1 are white or bluish white, examples of which are Sirius, Regulus, Vega. Their spectrum is crossed by many fine lines. There are four dark ones which are always prominent. The first is in the red, the second is in the greenish-blue, while the third and fourth are in the violet. These are due to hydrogen, and correspond exactly with the four brightest lines $H\alpha$, $H\beta$, $H\gamma$, $H\delta$, constituting the spectrum of terrestrial hydrogen. The dark line C corresponds with the line $H\alpha$; the F line with $H\beta$, the line near G with $H\gamma$; and the line small h with $H\delta$. In the spectrum of these stars, there is also seen a dark line coinciding with the sodium line D. Faint lines are noticeable in the green portion. These indicate iron and magnesium.

The spectrum of Type II exhibits many small black lines, caused by the absorption of metallic vapours in the star's photosphere. These are yellow, and are called solar stars on account of their spectrum resembling that of the Sun. The late Sir William Huggins remarked, "The great interest of these stars is that they appear to be suns in the same stage of development in which our Sun is." Capella belongs to



STELLAR SPECTRA.

From a photograph taken at Harvard College Observatory.

this class. The F line of hydrogen is not nearly so strong in this type as it is in the first. The calcium bands H and K are strong.

Type III constitutes stars that shine with a red light, examples of which are Betelgeuse, Alpha Herculis, Beta Pegasi, Antáres, Mira Ceti. It is very remarkable to find no hydrogen lines in C and F. The hydrogen line Hβ however is quite apparent in Mira Ceti and others. The light of most of the stars of this class constitutes red, yellow, and green rays.

Type IV stars are of deep red, but there are no striking examples.

CLASSIFICATION OF SPECTRA BY HARVARD OBSERVATORY.

At the Harvard College Observatory some years ago, 100,000 stars were examined spectroscopically, and as the result of minute research a more specific and serviceable scheme of classification for stellar spectra was put into form. In this new system the classes coinciding with the progressive stages of stellar evolution are shown. These types are marked by the letters of the alphabet beginning at A and concluding with Q. Since then the classification has been modified to a small extent, and the principal divisions now are B, A, F, G, K, M.

Plate VII illustrating typical stellar spectra includes the lines between the wave lengths 3,800 to 5,000, hence they are usually in the visible part of the spectrum.

Prolonged research has led to the belief that nebulous matter condenses under the self-attraction of its own material, rises in temperature, getting constantly hotter, until it forms the B type stars of very high temperature and low density. Hence, B type stars are placed first to represent the earliest stage of their evolutionary life-history, and are younger than those belonging to class A. They are sometimes named helium or Orion stars, because the lines of helium are conspicuous in the Orion group. They attain their

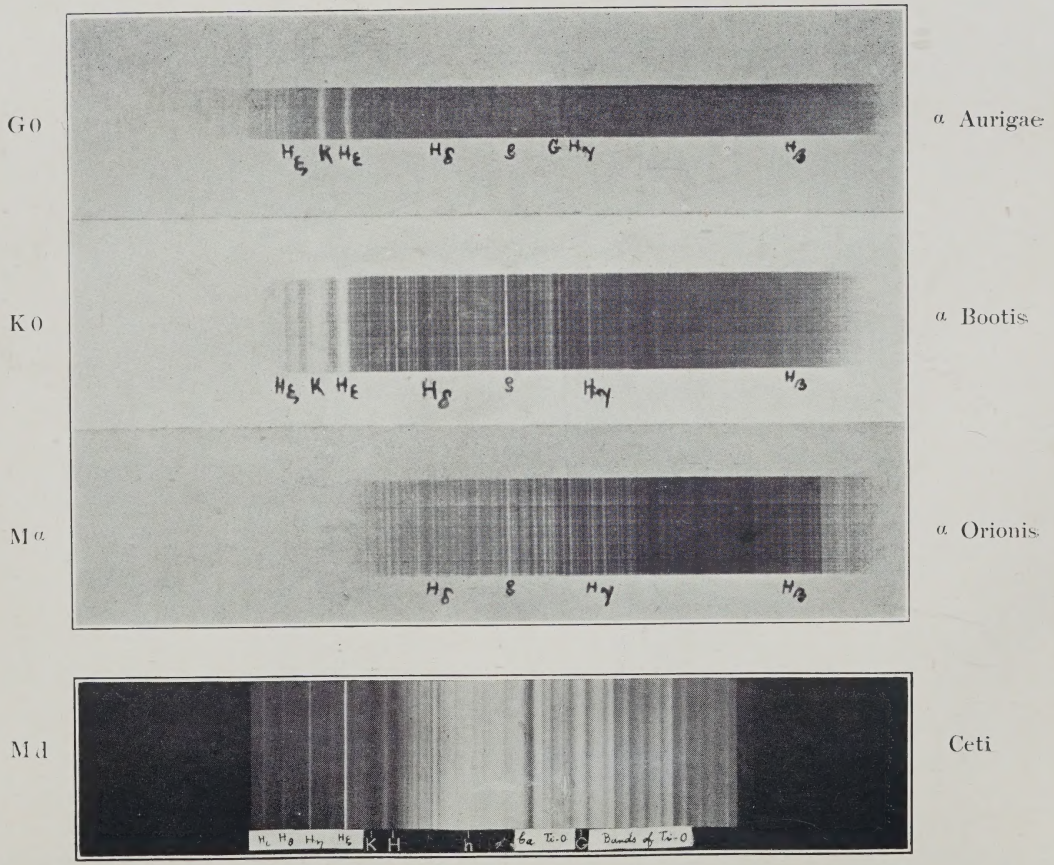
greatest intensity in class B2 and diminish in intensity in classes B8 and B9. The most prominent examples are Rigel, Bellatrix, Delta, Epsilon, Zeta Orionis and Beta Lyrae. Class B has ten subdivisions designated as B0, B1, B2, etc. It is supposed that the white helium stars reach the enormous temperature of 15,000 degrees Cent.

Type A stars are still further developed and belong to class 1. In this type hydrogen lines are very prominent, while lines of helium are faint or are not apparent. It is noticeable that the calcium K line is faint. The typical stars are Sirius and Vega. It is supposed that the white hydrogen stars reach temperatures of at least 11,000 degrees Cent.

F type stars are later in their stage of development than the preceding, and are intermediate between Secchi's first and second types, *i.e.*, between white and yellow stars. They probably attain temperatures of 8,000 degrees Cent. Hydrogen lines are still as intense as in class A, and metallic lines increase in intensity. The calcium line K is the most prominent feature. Alpha Carinae (Canopus), Alpha Canis Minoris, Alpha Aquilae and Polaris are striking examples of this type.

G type stars are representative of Secchi's type II, and are similar to our Sun in spectrum and at nearly the same stage of development in their evolution. The lines of hydrogen are not nearly so intense as those in A and F. The most prominent lines are those of calcium H, K and the band G. The typical star is Alpha Aurigae. The stars of this type reach temperatures of 6,000 degrees Cent.

K type stars occupy a middle position between Secchi's II and III type. Their spectra are mid-way between yellow and red stars. The lines of hydrogen C ($H\alpha$) and F ($H\beta$) are only one-twelfth as strong as in Sirius. The H and K calcium bands are most intense, while the iron line G 4,308, calcium line small g 4,227, and $H\gamma$ 4,341 are prominent. The typical stars are Alpha Bootis, Aldebaran and Alpha Ursae Majoris.



STELLAR SPECTRA.

From a photograph taken at Harvard College Observatory.

M type stars which are the same as Secchi's type III have a banded spectrum. The dwarf stars of this type are approaching stellar old age and extinction, while the giants, like Alpha Orionis, are young stars. In some of the stars the lines of hydrogen appear to be very faint, while in others they are bright. The most striking example is Omicron Ceti or Mira. It is supposed that these stars reach temperatures of 3,000 degs. Cent., or 5,400 degs. Fah. In Mira, bright hydrogen lines are very strong during the time of maximum brightness. This may be due to the outburst of hydrogen gas at the time of the star's greatest activity.

In O Ceti the chief characteristic is the series of bands of titanium oxide, which indicate such a lowering of temperature as to permit of the formation of a chemical compound. It is noticeable that the bright hydrogen lines are not all equal in intensity.

In Alpha Canis Minoris the chief metallic lines are indicated, going to the right from H in increasing wave-lengths 3,990 Ti, 4,005 Fe, 4,031 and 4,033 Mu, 4,046 Fe, 4,078 Sr, 4,173 Ti, 4,227 Ca (g).

Briefly, the order of sequence in the various classes is helium, hydrogen, calcium, metallic lines, and a banded spectrum, corresponding to blue, white, yellow, and red stars.

RUSSELL'S THEORY OF STELLAR EVOLUTION.

A more recent theory of stellar evolution generally adopted, is that advanced by Professor Russell, called the Giant and Dwarf star theory, according to which the order of stellar evolution is $\frac{\text{Giants}}{\text{MKGFAB}}$ $\frac{\text{Dwarfs}}{\text{AFGKM}}$ for the most massive stars. It is worth while pointing out in passing, that the late Sir Norman Lockyer also supposed an ascending and descending series of stellar spectra depending on temperature. According to this theory, type B indicates the stage of maximum intensity, light, and temperature. This may be best understood by following the evolution of a star from its nebular condition.

As the condensation of the nebula of a very low

density and at a low temperature goes on, the volume diminishes and temperature increases, until the star becomes visible, a very red star of low density, a giant star of type M. As condensation advances, the volume continues to diminish, the density and temperature to increase, the loss in surface area being counter-balanced by the increase in surface brightness. We have thus giant stars formed, belonging to types K G F A B. The density, temperature, and surface brightness increase quickly, passing through all the spectral types from M to B. The density increases, while the temperature rises from 3000° to 20,000° Cent. Conden sation, however, still goes on, though not so rapidly, and the loss of radiation commences to overpower the gain of energy by condensation. The temperature commences to fall, and the star now passes through the same stages in the reverse order on the descending temperature scale through A to M. But in this stage the density increases, while both volume and surface brightness diminish. Consequently, the absolute magnitude diminishes at a fast rate, resulting in the dwarf stars of the later types. After passing through the M stage the star gradually becomes invisible. This is the development followed by the more massive stars. Stars of small mass do not attain such high temperatures. The result is, they do not rise beyond the A, F, or G type, while stars which have very small masses may not be visible at all.

Professor Campbell, in his remarkable researches during the past few years, has discovered the extraordinary fact, that the average velocities of the different classes of stars vary according to their type. He finds that stars, class B, have an average speed of five and a half miles per second, while their average distance from us is 500 light years. Stars belonging to class A travel at the rate of six and a half miles per second, and are, on the average, distant from us 200 light years. Stars of class F move with an average velocity of nine miles per second, while their average distance from us in light years is 100. Stars classified

G have, on the average, a velocity of ten miles per second, and are distant from us on the average 150 light years. Stars of type K have a mean velocity of ten and a third miles per second, and are, on the average, 225 light years distant. Stars belonging to class M have a mean velocity of ten and two-third miles per second, while their average distance from us is 300 light years.

These investigations made by Professor Campbell, show that in accordance with the type of the stars' spectrum there is a gradual increase both in the speed and distance of the stars. From his interesting researches, we learn that the stars belonging to class B, are on the average, at an enormous distance from us and are very massive, the majority of them being found in or near the Milky Way ; whilst stars belonging to classes F and G, showing spectrum similar to that of our Sun, are near our Solar System.

Sir Frank W. Dyson has examined the distribution of stars contained in Carrington's Circumpolar catalogue, and finds that yellow stars are the nearest to us, eighty per cent of them being nearer than 300 and 500 light years, ten per cent being nearer than 300 light years, while ten per cent are further away than 1,600 years. The distances of the blue and red stars are found to be greater, the latter being more than 3000 light years. He also finds that the stars vary considerably in intrinsic brightness. The red stars for example are, on the average, 100 times brighter than the Sun. About ninty-five per cent of the stars from the 1st to the 11th magnitude are brighter than the Sun. It has been found that the stars thin out considerably at a great distance from the Sun.

As to the dimensions and form of the stellar universe, it has been calculated that its diameter measures between ten thousand and fifteen thousand light years, that it has a thickness of between two and three thousand light years, and that our Sun is not entirely in the centre of it.

THE NUMBER OF THE STARS.

Another point of interest is the number of stars in the universe. Observers of the heavens have often attempted to count the number of stars by means of powerful telescopes or by photography, and it has been conjectured by many that the universe may reach to a great distance beyond the boundaries at which stars have been detected. Astronomers have only been able to make an estimate of certain defined areas. By comparing these areas and making an approximation, the counts may be extended to greater portions of the heavens.

Sir John Herschel's estimates of stars were taken in different regions of the sky, and by comparing the number obtained in the various sections examined, he reached an approximation for the whole stellar area. His purpose in doing so was to find out how far the visible stars of the universe extended. One of his counts amounts to five and a half million stars, from the 1st to the 14th magnitude. Otto Struve made an estimate of twenty million stars of the same magnitude. The number generally counted has been fifty millions of stars visible in our largest telescopes.

If a photographic plate be exposed to the heavens for a sufficiently long time, it will record stars down to the 20th magnitude. Most of the asteroids from the 12th to the 16th magnitude, discovered within the past few years, have been detected by photographing the heavens with moderately sized telescopes. The small satellites of Jupiter and Saturn, which can scarcely be picked up by means of the most powerful telescopes, were found by photography.

To explain the boundaries of vision of our telescopes, we may commence with stars of the 6th magnitude, which are just faintly visible to the naked eye. A telescope with a two-inch object glass will show stars down to the 9th magnitude. A telescope with a six-inch object glass will show stars of the 12th magnitude.

A ten-inch object glass shows 14th mganitude stars. Of our more famous telescopes, there is the great Lick refractor, which makes visible, stars of the 17th magnitude. On Mount Wilson, California, the five-foot reflector extends to stars of the 18th magnitude; while the 100-inch reflector, recently erected there, shows stars even of the 20th magnitude.

The late eminent astronomer, Professor E. C. Pickering, Harvard Observatory, estimated eighteen million stars ranging from the 1st to the 15th magnitude. It is assumed that the extent of the visibility in our most powerful telescopes would, on the average, probably be about 2000 stars to the square degree over the entire heavens. If this estimate be correct, then we have 100 million stars from the first to the 17th magnitude inclusive. Large reflectors, using photographic plates of three or four hours exposure, might disclose 1,000 million stars down to the 20th magnitude.

LIMITATION OF THE STELLAR UNIVERSE.

Another point is the limitation of the stellar universe. During the last century the space-penetrating power of telescopes was increased to such an extent, that stars hitherto unknown were discovered; and it was taken for granted that the number would continue multiplying, until it was found that they were too numerous to be counted and that they were practically infinite. But it has been found that the number of stars seen in the giant telescopes, has not increased so much as was at first anticipated. In fact it has been noticed that in several portions of the sky, the exposure for three or four hours of a photographic plate, does not increase greatly the number of stars already known.

Careful observation reveals the fact that the stars are not distributed through space in an even or regular manner, but that as the distance increases, the number grows less. The stars are more abundant in the regions around Sagittarius, Ophiuchus, Scorpio, Aquila and

Cygnus; but in more distant parts of the heavens they become more sparse.

There appear to be very many faint stars which cannot be picked up by telescopes possessing the highest space-penetrating power, but past a certain boundary there is no apparent evidence of the existence of stars corresponding in number in any degree commensurate with those clearly visible within the area of space-penetrating power. If, for example, a seven-inch telescope showing stars down to the 12th magnitude were employed, it would be found that almost the same number of stars would be seen in the vicinity of Ursa Major and Ursa Minor as are seen with more powerful telescopes.

From this we conclude that no matter how much space-penetrating power may be increased, the number of stars already estimated in that part of the sky cannot be extended. By the aid of large telescopes, astronomers are able to discover faint stars even to the 16th and 17th magnitudes in many parts of the heavens. If therefore, stars of that small magnitude were really in existence in the neighbourhood of Ursa Minor and beyond it, they would be able to detect them; so we infer that very faint stars are not present there. We must accordingly conclude that our stellar universe, notwithstanding the fact that it is enormously great, is limited in extent.

GALAXY, DISTRIBUTION OF THE STARS AND THE STRUCTURE OF THE UNIVERSE.

Our last point is the Galaxy, distribution of the stars and the structure of the universe.

The Galaxy or Milky Way is a vast, broad, luminous band or belt stretching round the heavens almost in a great circle. When, however, a large telescope is turned upon it, it is found to be composed of countless multitudes of very minute stars which are too small to be separated with the naked eye. It is aptly called by Dr. Crommelin in his admirable book "The Star World," "the framework of the whole stellar system."

It varies greatly both in breadth and brightness, and, from the constellations Cygnus to Scorpio, it is divided into two nearly parallel branches. The stars are crowded into the form of a flat disc with its borders separated on one side, and the two halves of the divided portion more or less detached there. The Sun, with its retinue of planets, satellites, and asteroids, is situated in the interior central parts of this disc-shaped mass. When, therefore, we study the starry sky in all directions, we behold the sides of the flattened assemblage of stars in one direction of our sky, and its extended border in other directions.

It is found that most of the bright stars are situated in or near the Milky Way, and also that the telescopic stars are more closely crowded together there than in any other part of the heavens.

Astronomers have estimated the distance of the Milky Way to be about 4,000 light years from us, but Professor Russell has recently estimated, that in our northern sky it would take light from 20,000 to 50,000 years to reach us; while in the southern part of the sky, in Sagittarius where the Milky Way appears brighter, its distance is estimated at 100,000 light years.

The stars thin out to a great extent in parts of the sky which are situated far from the Milky Way, but towards the Milky Way the numbers gradually increase. It is thus apparent that the stars are not uniformly strewn over the heavens. They tend rather to congregate in large numbers, here and there, and to form connected streams. The late Professor Young believed that the light from the remotest stars in our stellar system, would require from 10,000 to 20,000 years to traverse the distance.

Wherever star groups are observed the natural assumption is, that they are attracted to each other by some mutual influence that is general throughout the universe. It seems from the distribution of those groups, that the stars which compose them are attracted by each other. The larger their mass the stronger is their attraction towards each other. There

can be no question that every star in this stupendous galaxy, is in a state of perpetual motion. Some believe that our stellar system is sweeping round the centre of some particular sun, but up to the present, no reliable information can be obtained regarding this notion. This, however, is very doubtful. No sun sufficiently massive for the purpose could possibly exist. The mass of a star has limitations, as internal radiation pressure would break it up if it were very large.

METHOD USED FOR MEASURING A STAR'S DIAMETER.

One of the most surprising discoveries that has recently been made in astronomical science, is the method of measuring the diameter of a star by means of the Interferometer. During the past few years, the dimensions of some stars have been measured by indirect methods. But the determining, by direct measurements, of the angular diameters of several stars by an application of the Interferometer suggested in the year 1890 by Professor A. A. Michelson, Director of the Physical Laboratory, University of Chicago, is now an accomplished fact. In the following year he applied the method at the Lick Observatory, to the measurements of the diameters of the satellites of Jupiter; but nothing more was done until the end of August, 1919, when he made some experiments with the 40 inch Yerkes telescope.

At the annual meeting of the British Association held at Cardiff in August 1920, Professor A. S. Eddington made the following remarkable prediction, "The star with the greatest apparent diameter is almost certainly Betelgeuse, diameter 0″.051, next comes Antares 0″.043; other examples are Aldebaran 0″.022, Arcturus 0″.020, Pollux 0″.013, Sirius comes rather low down with diameter 0″.007." Curiously enough, the measured angular diameter of Betelgeuse, made at the Mount Wilson Observatory by Messrs. Pease and Anderson in December 1920, was found to be 0″.046 instead of 0″.051 as predicted by Professor Eddington.

Professor J. S. Plaskett, by applying the most probable parallax, has calculated the apparent and actual diameters, the apparent and real brightness, and the mass of fourteen bright and faint stars.

Star	Type	Appar. Mag.	Appar. Diam.	Parallax	Mass	Bright-ness	Diameter.
Betelgeuse	M a	0·9	·044	·018	30	1450	235,000,000
Antares	M a p	1·2	·038	·013	30	1600	275,000,000
α Herculis	M b	3·5	·015	·007	30	710	200,000,000
Aldebaran	K 5	1·5	·027	·075	10	36	33,000,000
Arcturus	K 0	0·2	·023	·095	10	78	23,000,000
Capella	G 0	0·2	·0082	·071	4·6	78	8,000,000
Pollux	K 0	1·2	·015	·095	5	31	13,000,000
Procyon	F 5	0·5	·0048	·328	2	5	1,400,000
Sirius	A 0	—1·6	·0057	·376	2·5	26	1,430,000
Vega	A 0	0·1	·0026	·094	5	86	2,600,000
Rigel	B 8	0·3	·0019	·007	30	13,500	25,000,000
Krueger 60	M b	9·3	·0011	·260	·42	·002	360,000
Barnard's star	M b	9·7	·0009	·53	·023	·0004	155,000
Prox. Centauri	N	11·0	·0017	·76	·055	·00006	207,000

If the measured parallax of these stars be correct, then it follows that the first three have actual diameters 250 times greater than that of our Sun, and are unquestionably giant stars.

THE UNIVERSE A WORK OF DESIGN.

We cannot deny that this universe is a most gigantic and astonishing one, into whose fathomless depths our eyes can reach only to a very limited distance. The height of the heavens is, to all appearance, infinite; both height and depth of the starry sky are immeasurable; but the actual stellar area constituting our own universe, seems to have its limitations so far as we have been able to penetrate unfathomable space.

The distance round our Earth is 25,000 miles, to our Moon 240,000 miles, to our Sun 93,000,000 miles, to Neptune, the furthest away planet, 2,500,000,000 miles; while from that planet to Alpha Centauri the space is so prodigious that it would equal three thousand million of our Earth placed alongside of each other. We have seen that the distance of a number of giant

suns has been measured, from which we find that their light rays, with a speed of 186,330 miles per second; only reach us after travelling several thousands of years.

Those very distant suns probably belong to our own universe and are within the boundaries of the Milky Way. Nothwithstanding that, the farthest star in our universe is comparatively close to us when we view it in relation to the stars belonging to the universe outside our own.

The remarkable stellar magnitudes we have been dealing with, show that we occupy a very small place indeed among numberless worlds; and prove clearly to us the unlimited extent of the universe of the Omnipotent and Adorable Creator. It is absolutely beyond the greatest human mind to conceive the enormous distances of other universes in the boundless ocean of space. What can we conclude but that there is a sovereign power, a power greater and higher than man, controlling the destinies of all the worlds that encircle us? The perfect uniformity of astronomical laws, and the general aspect of stellar space attest this incontrovertible truth. By means of the telescope and spectroscope, we truly see suns in the making with their slow advance from one stage to another; and if this evolutionary process is constantly proceeding, if the same unalterable laws which regulate our Sun and planets also direct distant suns, stellar clusters, and nebulæ, the inference is that there must inevitably be a supreme all-originating Being under Whose guiding hand this development moves on through its vast and regular stages, controlled by the same immutable laws that fashion the wayside flower and "bind the sweet influences of the Pleiades." It is a positive certainty, that such astonishing development and such wise and consistent laws could not occur without design. There is undoubtedly an infinite mind behind all, Whose majesty and glory our finite minds can but dimly recognise, a supreme power that is transcendant, a wisdom incomprehensible

that has designed and brought into existence, and set in motion for wise far-reaching purposes this wonderful stellar universe of which our Solar System forms so small a part. When we penetrate the heavens so far as our vision can carry us with all the powers with which modern science has equipped us, we are overwhelmed with feelings of the profoundest wonder and awe, and we are constrained to acknowledge that those works of absolute perfection have originated from a Being infinite in power and wisdom, and Whose whole creation is stamped with an unfathomable love that cares for the infinitely small as well as the inconceivably great. One could not find a more appropriate conclusion to this particular part of our subject than these wise words of the great Sir Isaac Newton,

"This most beautiful System of the Sun, planets and comets could only proceed from the counsel and dominion of an intelligent and powerful Being, and if the stars are the centres of other like systems, these, being formed by the like wise counsel, must be all subject to the dominion of One, especially as the light of the fixed stars is of the same nature with the light of the Sun, and from every system light passes into all the other systems, and lest the systems of the fixed stars could, by their gravity, fall on each other mutually, He hath placed those systems at immense distances one from another."

LECTURE VI.

Binary Stars.

My purpose in this lecture is to mention a few of the facts known about binary stars. They have been intensely interesting objects of study for the past one hundred and twenty years, and to-day occupy a most important place in the investigations of astronomers. Sir William Herschel in the year 1802, described a binary as "a union of two stars formed together in one system by the laws of attraction."

It is necessary at the outset to make a distinction between a visual double star and a binary. When we speak of a visual double star we mean that the two stars which appear double, are only apparently so because they are nearly in line with each other. They seem to be close together when in reality they are far apart. Such a star is called an optically double.

A binary, on the other hand, is one that constitutes a separate system with a physical connection between its two members. Both stars are under the influence of their mutual attraction, and revolve round their common centre of gravity. Such twin stars, sweeping round each other in elliptical orbits, appear to the naked eye as one star. When the telescope, however, is fixed upon them, it is observed that the star which appeared to be single is really double.

A large number of the binary stars have the two constituent bodies so close together (less than one second of arc of angular measure from each other) that they can only be observed as separate members by employing very high magnifying powers with the best telescopes. Many of the binary stars however

are separated by five seconds of arc or more. To one who possesses a three inch telescope, such binary systems are readily visible, and become an intensely interesting study.

During the past thirty-five years, eminent astronomers, in examining binaries with the spectroscope, have discovered that many of them have two component stars which cannot be visibly separated with the largest telescopes. These are called spectroscopic binary stars, because when the spectroscope is directed to them, there is found to be a doubling of the spectral lines. This proves that each of the components are bright bodies. If the shifting of the lines in the spectrum shows that the components are moving constantly to and from us, this indicates that they are revolving in elliptical orbits around their common centre of mass. Further, if one of the component stars is a dark body or a body much less luminous than its primary, such as the companions to Algol, Sirius, Procyon and Spica, there will only be seen one set of lines in the spectrum, and the lines will just be slightly shifted from their normal position instead of being doubled.

The spectroscopic binary systems differ from the visual binaries in two points (1), their components are so much closer to each other than the visual binaries, that the highest magnifying powers of the largest telescopes can only show them as single stars. (2). Their periods of revolution are extremely short, some of which have been recently found to be only four hours.

DISCOVERIES OF BINARY STARS.

Riccioli, an Italian astronomer, was the first to discover a double star in the year 1650 A. D. Its name was Mizar; the second star in the handle of the Plough. Curiously enough, the primary star of this binary was also the first spectroscopic binary to be discovered. In 1889, the late Professor E. C. Pickering of Harvard College proved its existence by the variation in the lines

of the spectrum of Mizar. In 1656 Huyghens was able with his telescope of small magnifying power, to discern the three brightest stars of Theta Orionis in the Orion nebula. A few years after this discovery, Gamma Arietis and Alpha Centauri were found to be double by two different observers. Gamma Virginis, Castor and 61 Cygni were also discovered in the first half of the eighteenth century to be binary systems.

Sir William Herschel was the first to take up the study of double stars and as his telescope was much larger than those of his predecessors, he was successful in finding and recording a great many doubles. In making his observations, he noted two particulars, the fact of a companion star and the apparent distance between them. He published three catalogues containing in all 848 double stars, while his son, Sir John Herschel, published a catalogue of 380.

The next astronomer who made still further progress in the observations of double stars was Wilhelm Struve, Director of the Observatory at Dorpat, Russia. His catalogue, published in 1827, contains 3,110 separate entries. His work was taken up by his son Otto who, in 1843, published a list recording the discovery of 514 new pairs, a large number of which were close binaries. Some years later he discovered a few more, which increased the total of hitherto undiscovered doubles to 547.

Pre-eminent among all observers of double star astronomy was Professor Burnham, Chicago University. He discovered about 1,340 new pairs, and in 1906 he published a general catalogue of double stars containing 13,665, including practically every pair close or wide. Five years later, the Rev. T. C. H. Espin, of Durham, published a list of 1,356 new pairs, while in 1917, M. Robert Jonckheere published a catalogue of 3,950 and discovered 1,319.

Another eminent American astronomer who has made great advances in this important piece of astronomical work is Professor Aitken of the Lick Observatory. His examination of the heavens, has

rewarded him in the discovery of about 5,000 additional binary systems, the components of which are separated by an angular distance not exceeding five seconds of arc. The nineteenth century was marked by the discovery, through several eminent observers, of thousands of visual binaries; while this twentieth century is still more remarkable for the disclosure of spectroscopic binary systems which can only be revealed by means of the marvellous instrument, the spectroscope, probably the most potent factor in unravelling the mysteries of the universe ever discovered. Professor Campbell, Director of the Lick Observatory. and Professor Curtis, Director of the Observatory at Allegheny, were the first astronomers to publish a catalogue of spectroscopic binaries. It appeared in 1905, and contains entries of 140 separate systems. A list of 188 spectroscopic binaries discovered at the Dominion Astrophysical Observatory, Victoria, B. C. has recently been published by the Director, Professor J. S. Plaskett. The number discovered in all, now stands at 596. There is a marked difference between the visual and spectroscopic binaries in this respect, that the visual binaries are systems of huge size, and the period of time during which they revolve round each other occupies from 5 years to 2,000 years or more; while spectroscopic binaries are systems with small orbits, their periods of revolution occupying from a few hours to several years.

MEASURING BINARY STARS

I shall now mention one method by which a binary star can be measured.

In measuring a binary star, the quantities which have to be ascertained are the distance and position angle of the principal star called the primary and its companion. "Distance" means the apparent distance in seconds of arc between the centres of the discs of the two stars; while "position angle" means the angle at the brighter star between the line drawn from it to the north and another line drawn from it to the companion star.

The instrument employed along with the telescope in making these delicate measurements, is called the micrometer. There are several kinds used for binary star work. The simplest one consists of two fine parallel threads or wires which can be moved nearer or further from each other by turning a sensitive screw. The threads or wires are first placed so that they appear to touch or hide the objects whose distance is to be found. Then the number of the turns of the screw is recorded, which are required to make the two threads come into contact. Each turn or fractional turn of the screw, then represents a slight interval in arc whose value can be found.

Before mentioning some interesting binary systems, it may be well to state a few remarkable facts which have been discovered from recent observation.

Professor Aitken, in his study of the spectroscopic binary stars, finds that out of every eighteen stars as bright as the 9th magnitude, one of them is a binary system; and one in every three or four stars as bright as magnitude 5.5 is a binary. He assumes that binary systems probably number one-third of the whole stellar world. Further, the spectroscope reveals a large number of those binary systems to be really ternary and quaternary systems. Probably one in twenty have three or four components, and many of these are close binaries with a companion situated at a great distance. Of this large number, there are some whose components revolve round each other in circular orbits, and in almost surface contact, in the course of twenty-four hours or less; while there are others whose components revolve round each other in elliptic orbits, in periods occupying hundreds and even thousands of years. The former, on account of their short revolution periods, are found to belong to the earliest type of stars; while the latter, owing to their long revolution period, belong to a later type. The binary systems of the former are supposed to be, on the average, more than three times as extensive as the binary systems of the latter.

Another fact which has been discovered is, that

when the two components are equal in brightness, their mass is, as a rule, also equal. There are many systems, however, in which the brighter star is the more massive of the two.

We shall now turn our attention to some of the notable binary systems, and mention a few of the facts which have been discovered regarding them.

ALPHA CENTAURI.

One of the most interesting is Alpha Centauri, our nearest neighbour in the stellar system. It was not only one of the first stars to be discovered among binaries and the first to be noted among the stars in the southern hemisphere, but it also, along with 61 Cygni, was the first whose actual distance from our Sun was determined. It is composed of two brilliant suns, one of the 1st magnitude, and the other of magnitude 1.5 respectively, which revolve in a highly eccentric orbit. When they are at their furthest distance apart, they are situated twenty-two seconds of arc from each other. When they are at their nearest approach, they are only separated by two seconds of arc. The average distance between the two stars is about 2,160,000,000 miles, or more than twenty-three times the distance which separates us from the Sun. This binary system has a revolution period of about eighty-one years. Its entire mass is double that of the Sun ; and astronomers who have computed the proper motions of both stars, have found that the brighter one is the more massive of the two. The spectrum of the primary is an exact copy of our Sun ; while that of the companion belongs to an older type. Consequently its light power is less than that of its component, and is perhaps equal to that of our Sun. The spectroscope reveals the fact that it is travelling with a swift velocity of 650 million miles in a year.

In the year 1916, Innes, the astronomer at the Union Observatory, Johannesburg, discovered a faint red star of the 11th magnitude in the constellation Centaurus. The measures which he made, proved that

the star was moving westward at a swift speed of about 3.85 secs. annually, and was only two and one-half degrees from Alpha Centauri. Moreover, he found that its motion was precisely in the same direction, but slightly more rapid. Repeated observations showed that it was actually physically connected with the bright star. Photographs were taken both by himself and Voûte, a Belgian astronomer, assistant at the Cape; and on these being examined, it was found that the motion of the faint star was nearly parallel with that of Alpha Centauri. They also determined the parallax of the star as being 0″.78, corresponding to an actual distance of 4.3 light years.

CASTOR.

Castor is one of the most magnificent binary stars in our northern sky. It has an elliptic orbit of ordinary eccentricity. The magnitudes of the components are 2.5 and 3.5 respectively. Their distance apart is five seconds of arc; and, according to the latest calculations made, they revolve round their common centres of mass in a period of 347 years. The parallax of the system has been measured; and it is found to be thirty-three light years distant. Its entire mass has been computed to be twelve and one-half times that of the Sun.

An interesting discovery concerning the fainter of the two components of Castor, was made in the year 1896 by a Russian astronomer, Belopolsky. While he was occupying his time in measuring with the spectroscope the velocity with which the two components were moving to and from the observer, he found that the fainter component of the two had a variable speed. He noticed that at one time the star was approaching our system; while at another time it was receding from it.

As the result of a long course of observations, it has been found that this star goes through an entire revolution of change in three days. The cause of this change of speed is, that Castor is accompanied by an invisible and very close body, which has a mass

sufficiently large to move the bright star around in an orbit nearly circular once in three days. In 1904 Professor Curtis found that the other and bright component of Castor is similiarly accompanied by an invisible companion, which causes a variation in the velocity of the brighter star. It takes a certain period to approach us and another period to recede from us. The number of days required for the bright star and the invisible component to revolve wholly about their centre of mass is about nine and one quarter days. From these spectroscopic researches, we must conclude that Castor is a double double star, one of the most remarkable of quaternary systems known. As the brighter system has an eccentric orbit, and the fainter one a circular, it is probable that the former is further advanced in the process of development than the latter.

SIRIUS.

Two of the most interesting binary systems are Sirius and Procyon. Sirius has been called the "King of suns" because of its extraordinary lustre and surpassing magnitude. But this is because it is one of our nearest stars. There are many stars we know that vastly exceed it in real lustre. It is not only the most brilliant star in the sky, but is at least three times more luminous than an ordinary star of the first magnitude, and is computed to be five hundred times brighter than a 6th magnitude star. According to Professor Aitken in his book on "Binary Stars," Sirius emits at least thirty times more light than our Sun, and its parallax corresponds to 550,000 times the Earth's distance from the Sun, or fifty-one billions of miles. It would take more than eight and one-half years for light travelling 186,330 miles per second to reach us from this star. At this distance the Sun would appear as a star of the second magnitude, *i.e.*, equal to the Pole Star in brightness. There are only four other stars in the sky that are known to be nearer to us than Sirius.

By means of the spectroscope, it has been discovered that this star is receding from our system with a velocity of twenty-nine miles per second. It was considered by Kant, the distinguished German philosopher, as the central sun of the universe owing to its splendour and conspicuousness. His conclusion however, which seemed at that period to be quite a natural one, has been found to be incorrect, and now astronomers admit that they cannot distinguish any special star as the centre around which all the other stars revolve.

Sirius is a comparatively young star compared to ours, consequently it is a very gaseous and expanded body. Notwithstanding the fact that it is very much greater and more luminous than our Sun, its weight is comparatively light, its mass, *i.e.*, the total quantity of matter in it, being not more than 2.56 times that of the Sun's mass.

Another fact which makes this remarkable star a very interesting body to study is, that a number of years ago, astronomers discovered a companion or satellite revolving round it. The existence of such a body had been suspected for some years before; but it is perhaps worth noting that its actual discovery was a matter of chance. Its presence was disclosed by the power of its attraction upon the primary. Its motion varied in such a manner that it exerted a powerful influence upon the star. The eminent German astronomer Bessel, in the year 1834, was convinced that the periodical variations in the motion of Sirius, were brought about by the attraction of an invisible body revolving round it. Some observers had computed the orbit of the companion and its distance from the primary star on different occasions; but in spite of the fact that it was searched for very carefully, it could not be discovered even by the best telescopes. In February 1862, the eighteen inch telescope which was being built by Alvan Clark for the Chicago Observatory, happened to be directed to this brilliant star in order to test its power. No sooner was that done than the disturbing body came into sight, and

was found to be ten seconds of arc distant from the primary and precisely in the direction which had been predicted for that epoch.

The period of its revolution around the bright star was calculated to be forty-nine years, and within a few months of the period estimated by Bessel some years before the telescope had revealed its presence. The companion of Sirius is a star of the 10th magnitude, and is only 0.74 times as massive as the Sun.

Professor Aitken in his "Binary Stars" calculates that Sirius radiates more than 11,000 times the amount of light that its companion emits. The mean distance between the components is about twenty times the Earth's distance from the Sun. Owing to its orbit being highly eccentric, the distance of the smaller body from its neighbour varies from 800,000,000 to 3,000,000,000,000 miles. The last time the companion was at its nearest approach to Sirius was in the year 1894. It was so close to the primary, that even the most powerful telescopes could not detect it. Its next near approach will occur in 1943.

Astronomers in general are of the opinion that this invisible companion is a very old and nearly extinct sun far gone in decrepitude. We thus see that Sirius is a real binary star, the two components being physically connected and forming a binary system, *i.e.*, it reveals a smaller star revolving round a larger, or both of them revolving round their common centre of gravity.

PROCYON.

A similar irregularity in the proper motion of Procyon was observed in 1840 by Bessel. About the close of the year 1844 he solved the problem of irregularities in the motion of this sparkling sky gem, so efficiently, as to convince him that its vagaries arose entirely from the attraction of an invisible body or partially extinct sun. Dr. See, of Washington Observatory, made a number of investigations, and as the

result of his researches he found, not only that the faint companion revolves round its primary in forty years, but also that its average distance from the primary is twenty-one times the Sun's distance from the Earth. The companion is of the thirteenth magnitude, and its apparent distance from the primary is only five seconds of arc. The combined mass is calculated to be six times greater than that of our Sun; while the mass of the satellite itself is equal to the Sun's mass. Its parallax corresponds to a distance of ten light years; and, according to the late Professor Vogel, it is approaching us at the rate of six miles per second.

61 CYGNI.

61 Cygni, the second nearest star to our Solar System, is distant from us ten light years. The Sun, placed at this distance, would shine as a 3rd magnitude star. 61 Cygni is another of the binaries with a companion revolving round it. The magnitude of both stars is 5.5 and 6 respectively; while their apparent distance from each other is fifteen seconds of arc. Both stars move in an eccentric orbit.

This binary system has a very swift motion of five seconds of arc annually or nine minutes of arc in a century. This is equal to a velocity of fifty miles per second.

GAMMA VIRGINIS.

One of the brightest and most remarkable of binaries, is Gamma Virginis in the constellation Virgo. The magnitude of each component is three, and their angular distance apart varies from one-half second of arc to six seconds or more. The companion star makes a complete revolution round the primary in a period of 194 years. The eccentricity of its orbit is so great as to exceed that of any other stellar orbit known. The parallax of this system has been measured, and is found to correspond to fifty-two light years. Were our Sun placed at the distance of this binary, its luminosity would be reduced to a star of magnitude

6.5. The combined mass of the two members of the system is computed to be fifteen times greater than that of our Sun. The average distance between the components is seventy-eight times that of the Sun from the Earth; but owing to the great eccentricity of the orbit, the distance varies very considerably.

KRUEGER 60.

Krueger 60 is near the 4th magnitude variable star Delta in Cephus.* It is a faint, telescopic star of the ninth magnitude. This binary system separated only by 2.3 seconds of arc has a swift annual motion of one second of arc. A third star is 34.5 seconds of arc distant from the primary. It does not appear to be in any way related to the binary, for it is found that the latter, in its rapid motion, is moving away from it. The mass of the primary is computed to be three-fourths of that of the Sun; while the mass of its companion is about one-eighth. The magnitude of the components has been estimated at 9.3 and 10.7 respectively. From spectroscopic observations made on these stars, it is found that they are in the age of decrepitude, as they have been classed among the dwarf M type stars. Professor Russell, of Princeton University, in making reference to them, says "They are nearing the end of their evolutionary history." From recent measurements which have been made regarding the distance of this binary, it has been found that it is one of our nearest neighbours in space. The parallax indicates a distance of twelve and three-quarter light years.

TERNARY AND QUATERNARY SYSTEMS.

There are a great many ternary and quaternary systems among the binary stars. They compose separate systems, and are connected by the bond of their mutual gravitation with each other.

* Professor A. Krueger, in his meridian observations, was the first to draw attention to this star, and recorded it No. 60 of a list of double stars.

GAMMA ANDROMEDAE.

One of the finest ternary systems is Gamma Andromedae, consisting of stars of magnitudes 3, 5 and 7 respectively. The first is separated from the second by ten seconds of arc; while the second is separated from the third by one second. The components revolve round each other in a period of fifty-four years. This represents a binary system revolving round a central sun.

ZETA CANCRI.

Zeta Cancri is a quaternary system. The primary and its companion are of magnitudes 5 and 5.7 respectively, and revolve round their common centre of gravity in a period of sixty years; while the third star, of magnitude 5.5, retrogrades slowly round the first and second in 600 years. The first and second are separated from each other by one second of arc, while the first and third are five seconds apart.

It is supposed that the third star is merely a satellite to a dark body or extinct sun which may possibly be the most massive of the system. We have here an example of a cold dark body with three brilliant suns whose luminosity is much greater than that of our Sun.

40 ERIDANI.

40 Eridani forms a remarkable ternary system. The magnitudes of the stars of this group are 4.9 and 11 respectively. The first two are eighty-four seconds apart; while the primary is three seconds distant from the third. The primary star has a very large proper motion of four seconds of arc annually, or fifty-five miles per second, and its companions are travelling with it. Spectroscopic observations reveal the fact that the companion stars revolve round the primary with a retrograde motion in a period of 180 years. The parallax of this ternary system corresponds to seventeen light years. According to this distance, it follows that the semi-major axis has a length of more

than four billions of miles. Consequently the orbit is as large as that of the planet Neptune; while the two faint stars are 43,250,000,000 miles from the primary. Professor Aitken supposes that the period of revolution of the binary about the bright star is 7,000 years.

E^1 E^2 LYRAE

E^1 E^2 Lyrae form a quaternary system. The magnitudes of the upper pair are 4.5 and 6.3 respectively; while the magnitudes of the second pair are 5 and 5.2 respectively. The stars of the former are three seconds of arc apart, while those of the latter are 2.5 seconds. The revolution of the former is computed to be 2000 light years; while that of the latter is 1000 light years. These two binary systems are found by the spectroscope to be very similar to each other in appearance, distance, and velocity of motion. They are supposed to form a twin system revolving round each other in a period of the order of one million years.

TRAPEZIUM IN ORION.

A very notable multiple system is the Trapezium in Orion, composed of four stars of magnitudes 6, 7, 7.5, 8. They are situated so near to each other, that they appear to the naked eye like a single star.

There are in addition, two very faint stars, each one of which is a companion of the brighter stars. The six stars are physically connected with the nebula.

MIZAR.

One of the finest and most remarkable binary systems in the heavens is Mizar. It is the middle star in the tail of Ursa Major, and is accompanied by a naked eye companion named Alcor. When, however, the telescope is fixed upon the pair, Alcor is found to be situated at a great distance from Mizar, and a very small companion is disclosed. Thus, instead of two stars being seen in the field of vision, there are four. In August 1889, the late Professor

E. C. Pickering of Harvard University, was observing the spectrum of several stars with the view of discovering the various chemical elements of which they were composed.

While doing so, he directed his spectroscope upon Mizar, and was surprised to find that the spectrum lines were double. Some time after, he noticed that the double lines closed up slowly; while a few weeks later they opened out again. He then devoted himself to a special study of the star, and learned that those lines opened and closed in a period of fifty two days. The conclusion he came to was, that two stars were revolving in the line of sight round a common centre of gravity. While they were alternately approaching and receding, their spectrum lines were opened out in opposite directions. But when at the end of fifty-two days they had accomplished one half of their orbital motion and were crossing the line of sight, neither approaching nor receding, their lines were closed up and remained single. Since then it has been found that the companions revolve round each other in twenty and one-half days.

It is interesting to note that this was the first spectroscopic binary system discovered.

In addition to this invisible companion, which can never be revealed by the largest telescopes, there is the visual companion shining, with a white light. It has an angular distance from the primary of fourteen seconds of arc.

The faintly visible naked-eye companion named Alcor, of the 4th magnitude, is also a member of this superb Mizar family, although some observers are uncertain whether it is physically connected with the great Mizar System or not. It is quite apparent, however, that it is a real member of the group, owing to the fact that both its proper motion and its direction are precisely the same as those of Mizar. Up to the present no approach to the primary star has been actually observed, but that does not negative its affinity to the system. If it be revolving in an orbit,

that orbit cannot have less than a period of one million years. Small and unimportant as that star seems to us, it is a gigantic sun many times greater than our own, and its huge mass must exercise a very powerful force on the other three suns of the vast stellar system.

SPICA, CAPELLA AND BETA AURIGAE SPECTROSCOPIC BINARIES.

Three typical spectroscopic binary systems are Spica in Virgo, Capella and Beta Aurigae.

The companion of Spica has been found to be a partially extinct sun, revolving round the primary at the rate of fifty-five miles per second in a period of four days.

According to the late Professor Vogel's calculations the mass of the system is about three times that of the Sun, and the distance between the components about 6,500,000 miles. The system is approaching us at the rate of nine miles per second.

The spectrum of Spica belongs to the B type spectrum, so it is at present in an early stage of its evolution as a light-giver.

Capella is a spectroscopic binary system consisting of two components with a revolution period of 104 days. The orbit is found to be nearly circular. Vogel computed the distance between the components to be about 53,000,000 miles and the system to be receding from us at the rate of fifteen miles per second. It is interesting to note that by means of the Interferometer at Mount Wilson, the distance and position angle of this close pair can be measured.

The parallax of Capella corresponds to a distance of thirty-four light years. If the measurement be correct the star is 250 times more luminous than the Sun. Were our Sun placed at that distance it would shine as a star of magnitude 5.5. Its spectrum resembles that of our Sun, in fact it appears to be identical with it in physical constitution. Like the Sun it is yellow in colour, and ruled from one end of the spectrum to

the other with innumerable dark lines. This system has an additional interest owing to the fact that seven years ago there was discovered by means of photography, a faint star of magnitude 10.5 which was found to be physically connected with Capella. It has almost precisely the same motion both in direction and amount and is computed to be 11,000 times the distance of Earth-Sun from the primary.

The third notable spectroscopic binary is Beta Aurigae, four degrees east of Capella. It is a star of the 2nd magnitude, belonging to spectrum Class A, and is a little further advanced in development than Sirius.

On one occasion, when the late Professor Pickering was studying the spectrum of this interesting binary system, he observed that the lines quickly broadened, and in several hours thereafter they became double. After a short interval they returned to their ordinary position. He at once found, from the behaviour of the lines, that two stars, each approximately equal in mass and brightness, were revolving round each other in a practically circular orbit in a period of 3.96 days, with a velocity of 120 miles per second, and separated by only 15,000,000 miles from centre to centre. The parallax of this spectroscopic system corresponds to a distance of 136 light years. Were our Sun placed at that distance it would only appear as a star of magnitude 6.5. Since the parallax has been determined there are other elements of the system which can be calculated. The two bodies are very large and nearly equal in size, each being 2,250,000 miles in diameter, or three times the diameter of the Sun.

This is a system in which tidal friction has a very retarding influence over the surfaces of both bodies, for they are gradually receding from each other, and their periods of revolution are becoming longer.

ORIGIN OF BINARY STARS.

We shall now conclude this lecture by considering briefly one of the most important points in connection with the subject of binary stars, *i.e.*, their origin.

Three theories have been advanced as to their genesis, viz., the Capture Theory, propounded originally by the late Dr. Johnston Stoney; the Independent Nuclei Theory, put forward by Laplace; and the Fission Theory held by Darwin, Poincaré, and See, and supported by Professors Campbell and Aitken.

The first is, that two stars, which had at first been unrelated, might approach each other under such conditions as would induce them to turn aside from their respective paths and compel the one to revolve along with the other in orbits about their common centre of gravity. This, however, is only possible if we assume a resisting medium or some similar retarding agency.

The second theory is, that the matter in the original nebulae might condense into two nuclei or masses, separated by distances usually existing between the centres of the primary star and its companion.

The third is, that a single star in its first nebulous stage, or even later, might divide into two, each of which would at first revolve in surface contact.

The first theory could only hold in a very few instances of binaries, and would be absolutely irreconcilable with the known facts regarding close pairs revolving in orbits with relatively slight eccentricities, and sometimes none at all.

The second and third of these theories seem to be more plausible than the first, owing to the assumption that binary systems were evolved from gaseous nebulæ. We may assume on this basis that the mass, as a function of the speed of rotation, will change its various shapes, such as a spheroid and an ellipsoid, and at a certain point in its early stage it will break asunder into two comparable masses, and that these masses, condensing, will in the course of time, develop into binary stars. The late Sir George W. Darwin held that if the binary system, after its immediate disruption from the nebulous mass, is to be a permanent one, the two masses must be relatively

large. At the commencement of their life-histories, these two masses will revolve in surface contact with a practically circular orbit; but with advancing time the agency of tidal friction will cause the two masses to separate swiftly at first. After enormous ages, however, their speed will be less rapid, and the orbit will become an elliptical one. Those whose orbits have a short period of five or six days, appear to be circular or nearly so, and, according to the theory of stellar revolution, are the youngest stars, while those, whose periods of revolution are long, are widely separated; and consequently they are progressively older and have eccentric orbits.

The numerous instances in which drawings and photographs of nebulae show plainly the existence of two or more nuclei, would seem to point to stages in the evolution of binary or multiple stellar systems; but division of a rapidly rotating stellar body would easily occasion fission of its mass. In view of the evidence advanced, the fission theory seems to be the most likely, though it is probable that all binaries are not evolved in the same way. Those like the eclipsing binaries, where, in some cases the pair are nearly in contact, appear to have a common origin; but in the case of wide, visual binaries, there seems to be a different mode of origin and method of development.

Professor Jeans holds that reciprocal action with other stars, is the only efficient instrument for lengthening considerably the revolution period of a binary star. He instances, Beta Lyrae and Alpha Centauri, whose periods are 12.9 days and 81.2 years respectively; and considers as untenable, on dynamical grounds, the theory generally held that the former binary will, in the future ages, develop into a system similar to Alpha Centauri; his reason being, that such a development would require an angular momentum of twelve-fold power, and that there is no source of new angular momentum available. He therefore supposes that in accordance with the dynamical theory, Beta Lyrae can

never develop into a long period system like Alpha Centauri, but that Alpha Centauri may have developed out of a system similar to Beta Lyrae in the past ages, when it was in an early stage of its evolution, but whose period has been lengthened by coming in contact with other stars. He assumes that there was a time in the history of the universe when the stars were much more crowded than they are now. Consequently, near approaches of stars were more frequent, resulting in the increased eccentricities and periods of the long period binaries.

I have been utterly unable in this brief lecture to cover even a small fraction of the ground required for an adequate treatment of the subject of binaries, but I hope sufficient has been said to give some faint idea of the vast number and the enormous extent of these systems travelling through illimitable space. The ternary and quaternary systems are, in my opinion, among the most wonderful revelations that have come to us from the study of astronomy. The remarkable fact that two, three and four suns revolve round each other, or round their common centre of gravity, is, even to the unimaginative mind, a most sublime conception. In our own System we have one Sun whose radiant splendour and beauty have been not only the theme of the poets of all ages, but the inspiration for possibly the oldest and most persistent form of nature worship that we know ; but when we think of not one, but several resplendent suns, revolving round each other in stately and dazzling procession, it is difficult to imagine anything more august or overwhelming in the whole range of God's marvellous universe. And when added to this, we have every reason to believe that a number of planetary bodies, many of them far exceeding in size our own solar satellites, travel round these suns in swift motion over enormous circumferences, we may well join with the eloquent divine, the late Rev. Dr. Thomas Chalmers in his tribute to the majesty and vastness of the universe in which we live.

" In yon gilded canopy of heaven we see the broad

aspect of the universe, where each shining point presents us with a Sun, and each Sun with a system of worlds where the Divinity reigns in all the grandeur of His attributes, where He peoples immensity with His wonders and travels in the greatness of His strength through the dominions of one vast and unlimited monarchy."

LECTURE VII.

Variable Stars.

Variable stars have been objects of great interest and admiration to men ever since the discovery, by David Fabricius of the Netherlands, of the periodic variation of Mira Ceti in 1596. In the early hours of August 13th of that year, he made his first observation of this star, and calculated that it was equal to one of the 3rd magnitude. He searched several catalogues for the purpose of finding it recorded, but in vain. In October it became faint and disappeared from view. His observations led him to believe that it was a new star, but, strange to say, he made no mention of it until eight years afterwards.

In December, 1638, while an astronomer named Phocylides Holwarda, was watching a total lunar eclipse, he noticed a new star of the 3rd magnitude in the constellation Cetus. In the following month, to his surprise, he saw it decreasing in brightness, and it continued to wane until it became lost to view. In December, however, he saw it again quite distinctly, and later on published his observations. The situation where the star was discovered in 1638, was compared with that where, in 1596, Fabricius had first seen the star already referred to, and it was then found that it was the same star that had appeared in the same place in the sky.

A further comparison revealed the fact that in this same region, Bayer, the inventor of the system of nomenclature of stars by Greek letters, had recorded in his chart a star of the 4th magnitude, which he named Omicron Ceti. This was the first occasion on

which it was known that a star could appear variable in magnitude, and at a certain time of the year could be visible to the naked eye and at another time be invisible, even with the aid of the telescope. In 1660, Hevelius of Danzig, watched the star carefully, and named it Mira (The Wonderful) and shortly after his published observations, a French astronomer began to study it diligently.

Bouilland was the first to observe that the light changes were irregular, for, in eleven months the star decreases in brightness from the 2nd and 3rd to the 9th magnitude. It continues invisible for a number of months and then rises slowly to its maximum brightness. Both Bouilland and Jacob Cassini found, not only that the period of its light was irregular, but that it does not rise to exactly the same stellar magnitude at every period; for, although it may attain the 2nd magnitude one year, it may not reach the 3rd or 4th magnitude the following year.

Some 35 years after this, additional interest was aroused in the subject of variable stars, primarily through the investigations of two English astronomers, John Goodricke, a deaf mute, and Edward Pigott. Algol, in the constellation Perseus, was next found to be a variable, and those two astronomers distinguished themselves in that century by recording the period of light changes of this variable, and also by discovering a number of new ones.

For two hundred years after that, the number of observed variables did not exceed two dozen. During the present century, our knowledge of them has been increased to a great extent by the application of photography to steller phenomena. The number has also been multiplied to thousands, and every year new ones are being constantly added to the list. Astronomers can now practically classify all variable stars into fairly definite families.

In our study of variables, we shall take, to begin with, a brief view of the subject on broad and general lines.

A variable star may be defined as one that passes through a change in brightness. Some stars undergo a change as great as 4, 5 and 6 magnitudes, and a few even greater, as for instance Chi Cygni which ranges from 4.5 to 13.5 magnitude, or 9 magnitudes; while others are only subject to a variation of one magnitude and even less.

METHODS FOR COMPARING VARIABLE STARS.

The change in brightness is noticed by comparing the light of the variable star with that of a set of standard stars which are assumed to be constant in brightness. The comparison may be made by direct eye-estimates of the comparative luminosity, or by means of a telescope. A variable star is compared for its magnitude in the same way as a star of constant brightness. The best way in which to compare a standard star with a variable, is to pick out the nearest one which appears equal to the variable in brightness. The most accurate comparison is made when both stars are in the field of the telescope at the same time.

CLASSIFICATION OF VARIABLE STARS.

All variable stars may be divided into four distinct classes, viz. (1) eclipsing variables, including Algol and Beta Lyrae, (2) short period variables or Cepheids, including cluster variables, (3) irregular variables, and (4) variables of long period.

Most of the stars belonging to the first class, are in the early evolutionary stage of their development. Those in the second class belong to all ages, from the earliest stage to that of decrepitude; while all the third and fourth classes are red stars. Professor Russell considers these to be giants, that is, they are on the ascending hand of the curve representing stellar evolution.

We shall now make a summary inspection of each of these classes.

(1) Eclipsing variables. The typical, eclipsing variable star is Algol. There are known to be about 150

variables of this type, and they are called Algol variables. They are all marked by their short periods, the majority of them being less than five days. In 1783, Goodricke discovered that the light fluctuations of Algol were periodic. In 1669 Montarari detected the rise and fall, but did not take notice of the times when those changes took place. It was supposed from the Arabic name, Al-Gol or El Ghoul the changing spirit or demon, that these variations had been watched at a much earlier period. It is hard to explain in any other way the very appropriate name which the Arabs gave it.

Goodricke suggested that these changes were the result of a large body revolving round the star. The period of Algol calculated by Goodricke was two days, 20 hours, 48 minutes. In furnishing a description of his observations and the determination of the period of Algol, he says: "If it were not perhaps too early to hazard even a conjecture on the cause of this variation, I should imagine it could hardly be accounted for otherwise than by the interposition of a large body revolving around Algol, or some kind of motion of its own whereby part of its body, covered with spots or such like matter, is periodically turned towards the Earth." For two and a half days the brightness of the star continues regular at 2.3 magnitude, but in four and a half hours it declines to magnitude 3.5; while in the next four and a half hours, it returns to its former lustre. When it appears as a star of 3.5 magnitude it shines with only one-third of the light which it has in its brightest phase.

The explanation of these light fluctuations is, that Algol has a less bright companion which periodically comes between the primary and the Earth and cuts off a part of the light. This variation of light is caused by an eclipsing satellite. After the satellite has moved in front, it will recede from us, while the primary will approach us; consequently (if the orbit be circular) the maximum radial velocity of approach will occur at intervals of one-fourth of the whole period of revol-

ution, or seventeen hours after the period of minimum brightness.

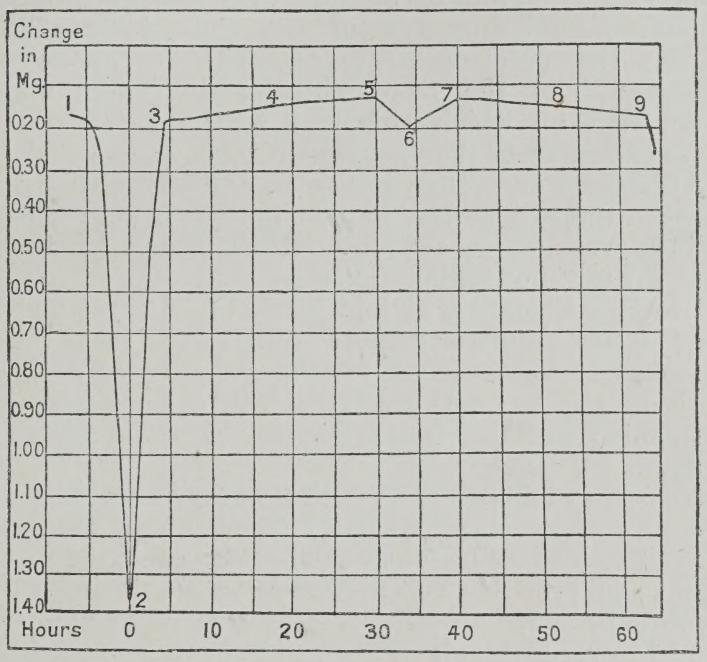


Figure 4—Light curve of Algol.

The light curve shows a sustained maximum, then a rapid descent to minimum, which lasts for an hour or more. This is followed by another rise to maximum of equal magnitude. In the figure, the numbers at the side indicate the change of magnitude during the light variation. The periods of time from one to three, is called the duration of the phase. This takes place during the time the companion star is moving in front of the primary, the eclipse being partial. The time of minimum shows the moment of greatest eclipse ; while the times 1 and 3 show the first and last contacts. During the remainder of the time the whole surface of Algol is seen: (1) stands for the commencement of the phase, (2) for the middle of the phase, (3) for the end of the phase, (4) for the moment of time mid-way

between the principal minimum and the secondary one, (5) for the commencement of the phase for the secondary minimum, (6) for the middle of the secondary minimum, (7) for the end of the phase, (8) for the point half-way between the secondary minimum, and the next following the main minimum, and (9) which coincides with (1) marks the commencement of the phase again.

Argelander and other observers, noted that the time between the two successive light minima is not regular. Efforts were made to find out the cause of these irregularities, but without success.

In 1888 Chandler, and in 1889 Vogel investigated the matter, and ultimately discovered that these fluctuations were caused by the presence of a third body in the system revolving with Algol and its companion in a practically circular orbit in a period of about 131 years.

Notwithstanding the fact that Algol is a ternary system, that which we see is the blended light of Algol and the close companion. The companion to the bright star probably rotates on its axis once in every revolution, and, like our Moon, keeps the same face turned towards Algol. This face is, of course, brighter than the opposite side by reason of the radiation which it receives from the primary.

In the years 1888 and 1889 the following interesting facts were adduced by Vogel concerning the system :

Diameter of Algol 1,161,000 miles, or 1·2 times the size of the Sun.
Diameter of companion 830,000 miles, or about the size of the Sun.
Distance between the centres of both primary and satellite 3,230,000 miles.
Orbital velocity of Algol 26·3 miles per second.
Orbital velocity of satellite 54·4 miles per seeond.
Mass of Algol $\frac{4}{9}$ solar mass.
Mass of companion $\frac{2}{9}$ solar mass.

Recent observations made by Professor Joel Stebbins, with a photo-electric photometer, give a new light curve for Algol, and there is every evidence that the orbit is a circular one. He determines the elements

of the eclipsing binary system, except the light of the third component.

	Sun = 1
Ratio of radii	0·85
Area of Algol obscured at minimum	0·700
Light of Algol	0·925
Light of bright side of companion	0·075
Light of fainter side of companion	0·045
Ratio of surface brightness of bright sides of bodies	0·059
Radius of Algol, radius of orbit = 1	0·207
Radius of companion, radius of orbit = 1	0·244
Mean density of system, Sun = 1	0·07
Duration of eclipse	9 h. 66
Phase of secondary minimum	34 h. 65

These elements prove that the companion is certainly not a dark body as some observers have supposed it to be.

It is also found that the satellite is a yellower star than the primary and belongs to spectrum G.

Professor Schlesinger has recently found a value of 0″.032 for the absolute parallax of Algol. This is equal to an actual distance of 102 light years, which means that its total light is about 200 times that of our Sun. According to the ratio of the masses, this gives the companion a surface intensity ten times greater than that of the Sun.

DELTA LIBRÆ.

There are other stars in addition to Algol that show these peculiar variations of light. One of the same type is Delta Libræ. At maximum brightness it appears as a star of the fifth magnitude, while at minimum it is only 6.2 magnitude. The obscuration by eclipse lasts twelve hours in each period of fifty-six hours. The length of time which it takes to fall from maximum to minimum is five and a half hours ; while its rise from minimum to maximum occupies six and a half hours. The orbit is supposed to be practically circular, and the system is found to be approaching us with a velocity of about thirty miles per second. According to recent measurements made by Professor

Schlesinger the diameter of the primary is two and three-quarter million miles, while that of the companion is two and a quarter million miles. He also finds that the two bodies are equal to three times the diameter of the Sun ; while their combined mass is one and a half times greater than the solar mass. The primary revolves round the centre of mass at an average distance of two million miles, while the companion revolves in its orbit at an average distance of three million miles.

It is assumed by Professor Campbell in his " Stellar Motions," that the two stars are rotating on their axes in the same time that they revolve about their orbits, always turning the same side to each other, precisely as the planet Mercury turns the same side to the Sun, or as our Moon turns the same side to the Earth. The reason for this is, that the tide-raising forces in a system of this kind, are necessarily enormous. If the pair was brought about by fission, the periods would probably be the same, and tidal friction would keep them so.

U CEPHEI.

Another notable star of the Algol class is U Cephei, discovered in 1880 at Moscow by Ceraski. Since then it has been made an object of frequent study by observers. Its period is fifty-nine hours fifty minutes. In four and a half hours the star falls in brightness from the 7th magnitude to that of 9.5. It remains at minimum brightness for two hours, and then rises to its ordinary magnitude at a slower rate than its decrease of light. The light fluctuations altogether amount to ten hours. It is a very remarkable fact, that the faint companion is much redder than the bright star. The only conclusion arrived at regarding this phenomenon is, that its temperature is lower than that of the brighter star. The spectrum of the primary belongs to Class A, and its colour is white ; while that of the redder companion, which eclipses it entirely at minimum, belongs to Class K.

Slight irregularities have been detected by means of the spectroscope, which seem to act upon the period of the bright star similar to those affecting Algol. The explanation is, that the primary and its companion revolve round a dark body in a period of 30.7 years.

A third example of the Algol type is Lambda Tauri, which varies in magnitude from 3.3 to 4.1, and has a period of three days twenty-two hours fifty-two minutes. The variability of this star was first proved by Baxendell in 1848. In 1897 Belopolsky discovered that it was a spectroscopic binary, and Professor Schlesinger of the Observatory at Allegheny, has recently found that there is a third body which revolves about the eclipsing system in a period of 34.6 days. The second body in this eclipsing variable is similar to the companion of Algol in being brighter on the side towards the primary. By means of the photo-electric photometer, it is found that this star is an eclipsing system with two minima and continuous variation between eclipses.

SUMMARY OF ELEMENTS OF LAMBDA TAURI.	SUN = 1
Ratio of radii of first and second bodies	0·75
Area of second body obscured at minimum	0·655
Light of first body	0·796
Light of bright side of second body	0·122
Light of faint side of second body	0·038
Light of third body	0.082
Ratio of surface brightness of bright sides of first and second bodies	3·7
Mass of first body Sun = 1	2·5
Mass of second „ „ „	1·0
Mass of third „ „ „	0·4
Density of first „ „ „	0·025
Density of second body of Sun =	0·024

There is another class of variables called the Beta Lyræ, which Professor Shapley and others have included recently among those of the Algol type, because they have been found to be eclipsing stars. Beta Lyræ exhibits variations dissimilar in their nature

from those of Algol, yet in some respects they present a certain resemblance to them.

Dr. Furness, in her "Introduction to the Study of Variable Stars," says, "It would appear that there is no dividing line between the members of the two groups of eclipsing stars, that in order of evolution the two components as they are first formed from the original mass, are possibly surrounded by the same gaseous envelope, and because of their small density and rapid rotation, become elliptical in shape. In the course of time, owing to tidal friction, they tend to separate and get further apart, so that they are no longer in contact."

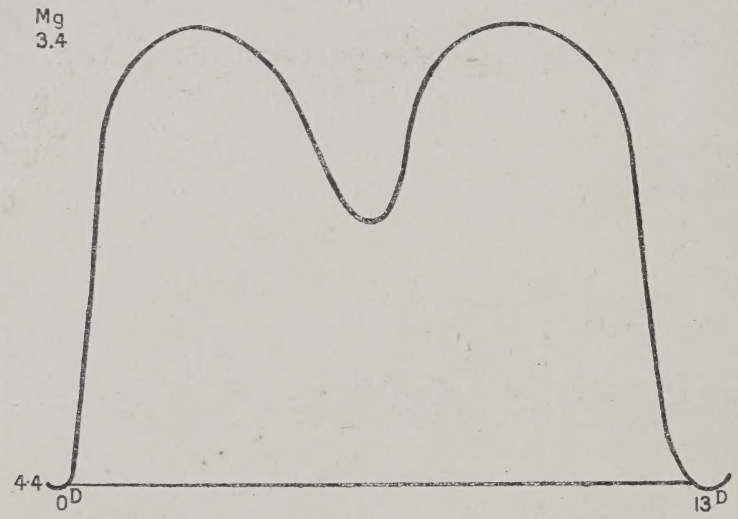


Figure 5—Mean Light curve of β Lyrae.

The light curve of Fig. 5, of 3.4 magnitude to 4.4 magnitude and extending from 0 days to 13, marks a sharp rise from minimum to maximum. It then falls to a secondary minimum. This is succeeded by another rise to a maximum of the same magnitude. When this star is compared with its near neighbour Gamma, a star of the same magnitude, it is noticed that sometimes both stars appear to be of the same

magnitude, while at other times Beta appears to be one magnitude fainter. The late Professor E. C. Pickering examined this system carefully, and found by the doubling of the spectral lines in the spectroscope, that there were two large gaseous suns whose densities were small, revolving very closely round each other. The masses of the two suns are found by Myers to be twenty-one and ten times respectively greater than that of the sun.

The spectrum of this eclipsing binary is a remarkable one, consisting of broad bands due to hydrogen and helium. Magnesium, calcium, sodium and iron are also prominent. This is convincing proof that these two suns are in a very early stage of stellar evolution and have just commenced their career as light-givers. As they grow older and the distance between them increases, the eclipses which at present occur frequently, will finally terminate, and as a result the light variations referred to will gradually disappear.

We have in this remarkable class of eclipsing variable stars, evidence of the fact that when two stars with a physical nexus are very close to each other and have a short period of revolution, they ear young stars; while those whose orbits are large and whose period of revolution is long, are in an advanced stage of development.

Similar variables of the Beta Lyrae type, but with much shorter periods are Υ Cygni whose revolution period is 36 hours. Its light range is from 7.1 to 7.9 magnitude, and its light fluctuations occupy nine hours.

U Pegasi—Variation from 9.3 to 9.9 magnitude. Revolution period nine hours.

Zeta Herculis—Period four days. Varies from 6.9 to 8 magnitude. Duration of phase 6 hours 36 minutes.

There is every reason to believe that these three eclipsing variables are suns whose surfaces are in actual contact.

CEPHEID VARIABLES.

We shall now turn our attention briefly to the Cepheid Variable stars, of which 93 have been registered. The typical star of this class is Delta Cephei.

DELTA CEPHEI VARIABLE.

Its brightness at maximum rises to magnitude 3.7 in 38 hours 36 minutes; while at minimum it falls to 4.9. These variations take place in a period of 5 days 8 hours 47 minutes.

There are other well-known variables of this Cepheid group, such as :

Zeta Geminorum, whose periodic fluctuation of light varies from 3.7 to 4.5 magnitude in 10 days 3 hours 41 minutes. This is a variable whose brightness increases less rapidly to maximum than it falls away to minimum.

Eta Aquilae varies in brightness from 3.5 to 4.7 magnitude in 7 days 3 hours 41 minutes.

S Sagittae from 5.6 to 6.4 in 8 days 9 hours 11 minutes.

Several interesting facts have been brought to light regarding these Cepheid Variables. The first is, that like Novae, they are found particularly in the Milky Way and its neighbourhood, (2) they are yellow stars whose spectra belong to Secchi's second or solar type. (3) Professor Shapley finds they are situated from us at enormously greater distances than those which have up till now been measured. The most remote Cepheids known are estimated by him to be nearly 20,000 light years distant, (4) they are characterized as being giant suns. Professor Russell assumes that the Cepheid cluster variables whose periods are about 7 days, are on the average 700 times more luminous than the Sun and their diameters 26 times larger ; while those whose periods are 40 days or more, have a luminosity 10,000 times that of the Sun, and (5) their light variation periods not only appear to be

regular and their light curves fairly constant, but their range of variation very seldom exceeds 1.5 magnitude, and the rise to maximum brightness takes place more quickly than the fall to minimum.

There are however some difficult problems regarding these Cepheids which cannot be explained satisfactorily. A great difficulty arises as to the nature of the physical process which causes these stars to vary in brightness. It is very doubtful if the Cepheids are binaries. A comparison of the light and velocity curve shows that the variation in light is not due to anything like an eclipse. Their light variations seem to be closely analogous in cause, though widely different in period, to those of long period variables, and are probably to be attributed to some unknown changes occurring in the stars themselves.

A theory due to Professor Harlow Shapley has found much favour. It is that of pulsation in the stars. According to this view, the observed facts in Cepheid variations, accord with the assumption that the light and velocity variations are caused by disturbances on a large scale on the radiating surfaces of single stars. Now it is found impossible to relate the velocity variations to orbital motions, but the variations in magnitude are synchronous with variations in spectral type in the stars themselves. Hence the hypothesis, that there are free oscillations or pulsations in the gaseous mass of a Cepheid variable. The sunspot period on the Sun may analogously be regarded as a pulsation. As to the origin of such pulsations, they may be due to the close approach to another body or to the perturbations of a dark companion ; but in the Sun the sunspot cycle or pulsation of eleven years is something intrinsic.

A third group of variables is the irregular. The stars belonging to this group are variable in light only to a small extent. So far as observation goes, they have no constant period. As light givers, they may be placed among the giant stars. Their spectra belong to class M. The following six stars are subject to slight,

irregular light fluctuations of one-half magnitude. Betelgeuse, Alpha Cassiopeiae, Beta Pegasi, Alpha Herculis, Rho Persei, Mu Cephei.

The last kind of variable stars are what are called the long periodic variables, ranging from sixty-five to nearly 800 days. Dividing this class into groups, we find that about 750 are registered, whose periods of light variation are between 200 and 400 days. A large number, however, exceed these periods. Range of light variation is much greater than for any other group of variables, with the exception of the Novae. The difference in magnitude between these stars at their brightest and faintest is frequently a difference of five magnitudes. This means a change in the brightness of a star to the extent of a hundred-fold.

Chandler has found a certain relation existing between the length of the period and redness. He says "The redness of variable stars is, in general, a function of the length of their period of light variation; the redder the tint the longer the period." Their light changes are always more or less irregular, and they are consequently not constant time-keepers: their rise to maximum brightness being ordinarily more rapid than their fall to minimum. Spectroscopic study of these stars reveals the fact that great changes are taking place in their spectra. It is quite apparent that they are not spectroscopic binaries. Owing to their small proper motions, it appears that they are very distant. The cause of variation seems to be embodied within the stars themselves and to have no relation whatever to dark suns revolving round them. The spectroscope discloses in these stars the presence of dense flutings of titanium oxide (denoting very low surface temperatures) and bright lines of hydrogen which are particularly strong during the time of maximum brightness.

The typical star of this class is the remarkable variable Mira. As the result of repeated observations, the length of time which the star takes to rise from minimum to maximum and back again to minimum is 332 days. It usually varies in brightness

from the 3rd to the 9th magnitude, and back to the 3rd in eleven months. Sometimes however it attains to the 2nd magnitude, and remains at that brightness for ten days, after which it falls to the 9th magnitude.

Professor Campbell in his "Stellar Motions," writes the following interesting statements regarding this strange and extraordinary variable. "It is not impossible that in this star and others of the very red stars, there is a struggle to form a crust over the surface. As the crust forms and covers an increasing proportion of the solar surface, the light must diminish, and it is not unreasonable to suppose, that the imprisoned gases and vapours immediately below the crust, increase in temperature and pressure, so that when a certain point is reached, the crust is broken through and destroyed, and the brightness of the star thenceforth increases rapidly up to maximum. If this is really the case, it would not be surprising to have the lighter elements, such as hydrogen, projected outwardly from the star's surface with great speed. As our central body loses its heat and assumes a strong red colour in the far distant future, it is not impossible that there will be a struggle to form a crust over the surface such as we may be witnessing in the red variable stars."

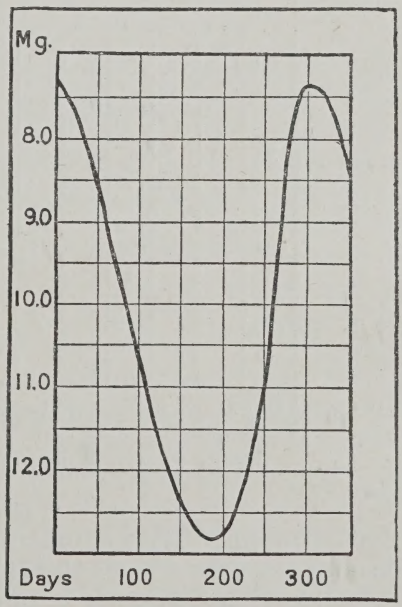


Figure 6—Mean Light curve of R Ursae Majoris.

There are many long period variables which are passing through great light variations similar to Mira. R Ursae Majoris, S Ursae Majoris, T Ursae Majoris, T Cassiopeiae, R R Scorpii, and R Coronae

Borealis, are striking examples. The mean light curve of the first (figure 6) shows the form of brightness, descending gradually to the 13th magnitude and rising very rapidly to 7.6 in a period of 302 days. The second fades away from maximum brightness 8.2 to minimum 11.4, returning again to maximum in 226.5 days. The third is similar to the first with an entire range of six magnitudes. The average period of T Cassiopeiae is 445 days; while the period from maximum brightness to minimum occupies 240 days, leaving 205 days for the other part of the period. Its brightness varies from the 7th to the 11th magnitude.

The secondary maximum in the mean light curve (figure 7) shows some irregularities.

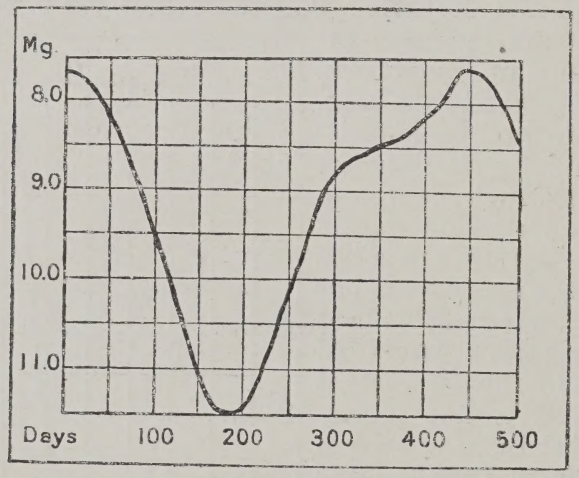


Figure 7—Mean Light curve of T Cassiopeiae.

R R Scorpii has a mean period of 283 days. Its brightness varies from the 7th to the 12th magnitude.

R Coronae Borealis is one of the most mysterious variables, owing to its great irregularities. Sometimes it remains stationary at magnitude 5.8 for a year; but at irregular intervals it declines rapidly in brightness to the 6th, 10th, and 13th magnitudes, and then

returns to its former lustre after intervals of months or years.

In trying to explain the wonderful phenomena observed in these long period variables, several theories have been advanced; but no precise one can be fixed upon which would enable us to attribute the light change to any one cause.

One theory is that the decrease of light in a star is due to a large body revolving in its orbit around the primary star in a plane passing through the Earth. This theory explains the cause of the variability in short period variables belonging to the Algol type, but it fails to explain the variability in long period variables. Were this theory correct, the light of the star would continue regular during one-half of the revolution of the large body, or one-half of the period of the primary. It is found, however, that only the Algol variables show these phenomena.

A second theory is axial rotation. Some observers think that variable stars may possibly be brighter on one side than on the other, and that as they rotate on their axes the bright and dark sides are alternately turned towards the Earth. This may account for a very slight variation of light, but it is difficult to imagine that a star can be a thousand-fold brighter on one side than on the other. As a further objection to this theory, it has been discovered that as some of these long periods variables rise to maximum brightness, bright lines are seen in the spectra. This shows that the sharp rise in brightness from minimum to maximum, succeeded by a gradual decline from maximum to minimum, is connected with light changes in the atmosphere of these stars.

A third theory is what is called the collision theory enunciated by Sir Norman Lockyer. It is briefly as follows: "These stars are not compact bodies like the Earth or Sun, but are swarms of meteorites, each attended by a satellite swarm revolving in a very eccentric orbit." "The periastron distance" (*i.e.* when the component is nearest to the primary star) "is so small,

that when the satellite swarm reaches that part of its orbit, the two bodies mingle to some extent, thus producing collisions and a consequent increase of light. As the satellite moves away from periastron the collisions become less numerous, and the light of the star dies away. Thus, the minimum brightness is the normal state and the maximum abnormal."

An obvious objection to this theory is that made by Miss Clerke in her "System of the Stars." "But the objection inevitably arises, that this state of things could not long subsist. Even if set on foot it would prove transient. By mechanical necessity the satellite swarm should speedily become extended into a ring, with, of course, complete effacement of variability. Thus, each maximum of a star, like Mira, if produced in the way supposed, would be feebler and more prolonged than its predecessor, until maxima and minima were brought to the same uniform level." The mere fact of the continuance of collisions would unquestionably exhaust sooner or later the satellite swarm.

The fourth and the most plausible theory of all, is the spot theory. For many years it has been supposed that the variation of light in a star, may be due to disturbances corresponding to those which take place on the Sun's photosphere. It is a remarkable fact that there is a distinct similarity between the curves of sunspot period and of long period variable stars. They are not only alike in form, but they are characterized by irregularities of a similar sort. In making a comparison of both curves, it is noticeable that their rise to maximum is steeper than their fall to minimum. They also show rapid or slow maxima and minima of unequal intensities. Sunspots, unquestionably, represent regions of lower temperature. In the light curves showing these phenomena, a maximum of spots on the Sun coincides with a maximum of light in the long period variable stars. From these interesting comparisons, it is quite apparent that these unusual occurences must emanate from the same cause.

In this comparison however, there is a very great

distinction made, and that is, that in long period variables the average variation of brightness is from five to eight magnitudes, while in the Sun, the variation caused by spots does not exceed one-tenth of a magnitude.

There is also a dissimilarity noticed in the spectra of the Sun and variables. The Sun belongs to G class; while all the long period variables belong to M class. Notwithstanding this fact, however, it may be mentioned that spectroscopists find that bands corresponding with those seen in long period variables, have also been discovered in sun-spot spectra, and that a distinct likeness can be drawn between the spectrum of sun-spots and long period variables. If this sun-spot theory be the correct one, then we must infer that in the greater proportion of these stars, the surface is periodically thickly covered with spots which lowers the temperature of those stars and also increases their density.

In concluding this imperfect survey of a wide field, it only remains to be said that there are other interesting matters relating to the subject of variable stars which one would like to mention did time permit. A great deal of telescopic and spectroscopic work must first be accomplished before we can learn more of the physical constitution of these variables, and of the strange laws under which their variations occur; but, while astronomy is one of the oldest of sciences, modern discoveries and modern methods have advanced the study of stellar phenomena to such a wonderful extent, that no limit can be set to the possibilities that lie in the unborn future.

Among these possibilities we may well include further revelations with regard to variables.

LECTURE VIII.

Novae.

We come, in our study for to-day, to the fascinating subject of Novae. These are extremely interesting stars and may well be made the subject of an independent lecture.

When we speak of a Nova, we are to understand by that a faint star that has suddenly received a great access of light in a place in the heavens where no star was previously known to exist. Some people may imagine it is a very small matter to see a new star blazing suddenly among the thousands which are visible to the unaided vision. Still, when we consider that all the stars we behold glittering on a cloudless winter evening, are suns like our own, many of them giants in size and enormously hot, shining by their inherent light at distances from us ranging from 300 light years and upwards, we must come to the conclusion that, after all, the instantaneous bursting into existence of a sun, where several hours previously it was not seen, is an occurrence which might naturally evoke the greatest interest in even the most casual observer of the heavens. Such an event is of infinitely greater significance, so far as our universe is concerned, than the appearance, unexpectedly, of a great comet in our Solar System.

Novae of a telescopic nature are comparatively common; while brilliant stars, equal in brightness to Sirius or Rigel are very infrequent. The usual course of events on the discovery of such a star is, the luminosity increases to a great extent in a day or two after its first observation. The star rises rapidly to maximum brightness usually during the first two days,

and remains a brilliant object for several days, after which it falls gradually in brightness, and at the end of a few weeks it is invisible to the naked eye. The different stages of its light curve take place at the same time as the change in the star's spectrum.

Records of stars as bright as Sirius, have been witnessed for many centuries. In primitive days, as well as in mediæval times, these apparitions produced feelings of reverential fear and amazement among all classes of people. Indeed, such radiant and sudden outbursts in the heavens, created greater terror and suspicion than any of the other celestial phenomena, save the more brilliant of the comets that blazed across the sky.

The first mention that has been made of a Nova is recorded in the year 134 B.C., in the Chinese Chronicles. This is now generally believed to have been a comet. Bright Novae are also recorded to have made their appearance in 48 B.C., 386 A.D., 393 A.D., 1012 A.D., 1230 A.D., 1584 A.D., but most of these are supposed to have been comets.

A brilliant Nova appeared in 1572 and was first seen by Tycho Brahe. It was named the "Pilgrim Star," and was first seen by this notable astronomer on November 11th 1572, in the constellation Cassiopeia. It received its name owing to the observations which he made regarding it, and its precise position in the sky. He says: "On quitting my chemical laboratory one evening, I raised my eyes to the well-known vault of heaven, and observed with undescribable astonishment, near the zenith in Cassiopeia, a radiant fixed star of a magnitude never before seen. In my amazement I doubted the evidence of my senses. However, to convince myself that it was no illusion, and to have the testimony of others, I summoned my assistants from the laboratory, and enquired of them and of all the country people who passed by, if they also observed the star that had thus suddenly burst forth. I subsequently heard that in Germany the common people first called the attention of astronomers to this great phenomenon in

the heavens, a circumstance which, as in the case of non-predicted comets, furnished fresh occasion for the usual raillery at the expense of the learned." (Lowell's "Evolution of Worlds.")

When the Nova was first witnessed by Tycho, it was brighter than the planet Jupiter, but it increased rapidly in brightness, until its luminosity was equal to that of the planet Venus, at inferior conjunction. At that time the new star could be located during the day. As it was a circumpolar star it could be seen at any hour. It began, however, to fall away in brightness very slowly compared with the rapid diminution of light shown by the majority of Novae. In the end of that year, it was equal to Jupiter in luminosity. In January the colour of the Nova commenced to alter, changing first to a yellow colour. In March, 1574, just before it became invisible, it changed again to a red tint.

Some people have tried to prove that this star was the same as the star of Bethlehem, and for this reason, as well as for its inherent interest, it has been studied to a considerable extent. Professor Langley says in this connection, "The evidence relied on is this, that bright stars are said to have appeared in this constellation repeatedly at intervals of from 308 to 319 years, though even this is uncertain, and as the mean of these numbers is about 314, which again is about one-fifth of 1572, it has been suggested, in support of the old notion, that the Star of Bethlehem might have been a variable, shining out every 314 or 315 years, whose fifth return would fall in with the appearance that Tycho saw and whose sixth return would come in 1886 or 1887." It is apparent that there is no proof available here to enable us to reach any positive or satisfactory conclusion, so this notion may as well be set aside.

The next bright Nova which made its appearance was observed in 1604. It is said to have been as bright as Venus at its maximum brightness. Professor Todd in his book "Stars and Telescopes" says: "This star remained visible for more than a year, and interested

the great astronomer, Kepler so much, that he made very careful observations and records of it." It was situated in the constellation Ophiuchus, and is named "Kepler's star," owing to the great interest which he took in it.

On June 30th, 1670, a Nova was discovered in Cygnus. When first seen it was of the third magnitude. Professor Todd in his "Stars and Telescopes," says that "During the two years that it was visible it underwent some remarkable changes in brightness."

A second Nova was discovered in this notable constellation in 1848 by an astronomer Hind; but it only reached 5.5 magnitude.

In 1860 a Nova appeared in the constellation Scorpio below the ruddy, 1st magnitude star Antares; but it never became brighter than the 6th magnitude, and consequently was scarcely visible to the naked eye.

In the Northern Crown a bright Nova made its appearance on May 12th, 1866. Its brightness increased within six hours, from an invisible star to one of the 2nd magnitude. It was for this reason called the "Blaze Star." On the day following, its light was seen to decline, and it continued to do so until the 16th, when it was at the 4th magnitude. After that date it waned rapidly in brightness; and in the end of the month it was only a telescopic star of the 9th magnitude. On investigations being made regarding the star, astronomers found that, after all, it was not a new one. Argelander had seen the star in 1855 and 1856, and on both occasions registered it as a star of 9.5 magnitude.

On November 24th, 1876, another Nova appeared in Cygnus, and increased in brightness to the 2nd magnitude. After remaining stationary for a few days it fell away to invisibility.

On August 19th, 1885, a Nova of the 7th magnitude suddenly became visible in the great nebula of Andromeda; and in recent years several small telescopic novae have been discovered in this nebula by Professor Shapley and others.

On January 24th, 1892, a Nova was detected in the constellation Auriga by Dr. Thomas Anderson, Edinburgh. On December 8th, 1891, Professor Max Wolf of Heidelberg photographed the part of the heavens exhibiting all the stars from the 1st to the 9th magnitude; but the Nova was not found on the plate. Between December 10th and February 1st, thirteen photographs of this region were taken at Harvard College Observatory. On December 10th the magnitude of the Nova was 5.37; on December 18th it seemed to have attained its maximum brightness of 4.4 five weeks before its discovery, for, on December 30th its magnitude was 4.6; while on January 20th it had declined in brightness to 5.2 magnitude. It remained visible to the unaided vision for two and one-half months, and then it rapidly declined in brightness. In August it rose again in brightness from the 13th to the 10th magnitude, and kept fairly constant for several years. It was noticeable, however, during the interval, that a nebula developed round the Nova, similar to a planetary nebula. It was discovered that this star was at an immense distance from us, and it is surmised that it came in contact with a gaseous body at a swift speed of several hundreds of miles per second. Several observations of the magnitude of the Nova after February 6th were obtained. On February 6th and 8th its magnitude was 5.15. On February 9th and 10th magnitude 5.1, February 11th magnitude 4.9. Between the dates 14th and 15th it rose to 4.5 magnitude, and afterwards gradually declined in brightness.

In the early morning of February 11th, 1901, a brilliant Nova, almost equal in brightness to the famous one seen by Kepler in 1604, was discovered by Dr. Thomas Anderson, Edinburgh. In relating his discovery, he mentions that after making some observations of stars in the early hours of the morning, he reclined for a few minutes at 2.40 a.m. and, on doing so, he lifted h s eyes to the constellation Perseus, and at once, at a short distance from Algol, he beheld

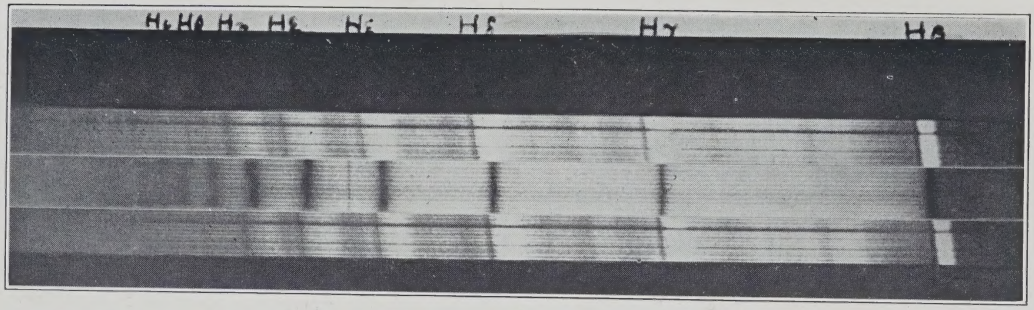
PLATE IX.

to face page 177.

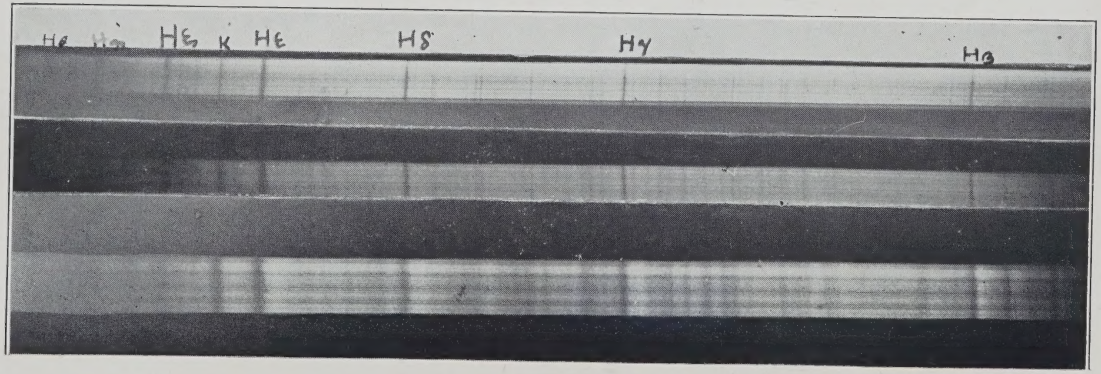
SPECTRA OF NOVA PERSEI AND CASTOR.

Stonyhurst College Observatory.

Castor



Displacement of dark hydrogen lines of Nova Persei with reference to Castor.



α Cygni	1920 Aug. 26
Nova Cygni III	,, 22
,,	,, 25

SPECTRA OF CYGNI.

Photograph taken by Major W. J. S. Lockyer, Ph.D., F.R.A.S.

a Nova of magnitude 2.7. In Hind's Astronomy ("Home University" edition), we are told that this star increased in brilliance at least four thousand fold in a few hours, and that this is proved by the fact that on a photograph of the same part of the sky taken only twenty-eight hours before the Nova was found, and showing stars down to the 12th magnitude, no appearance of the new luminary could be detected. For several years preceding 1901, a number of photographs had been taken of this region of the heavens, but not one of them showed any impression of a star exactly in the same place as the Nova. We have here indubitable evidence that a star, which had never been known before, suddenly became conspicuously visible within twenty-four hours. On the evening of February 22nd its brightness had increased to the 1st magnitude, and by that time it had been noted independently by a number of observers in different parts of the globe. On the following evening, February 23rd, it attained its maximum brightness, and was equal in magnitude to the brilliantly yellow star Capella. It was then several thousand times more luminous than a star of the 5th magnitude. On February 24th it began to decline gradually, its light fluctuating frequently. Observations with the spectroscope showed that the spectrum was crossed by many dark and fine lines. On 25th the spectroscope exhibited a dark-line spectrum with additional bright lines of hydrogen, helium, calcium, and iron. On March 16th its brightness declined to the 4th magnitude and its colour changed to yellow and red. On August 1st it became invisible to the naked eye. During that month it exhibited a spectrum corresponding to a gaseous nebula. In September there were signs of nebulous matter surrounding the star.

The most characteristic appearance of the light curve, was its rapid ascent on February 22nd and 23rd until it reached its maximum brightness on 28rd. It is quite obvious that the increasing brightness was very rapid, and that within one day its luminosity rose

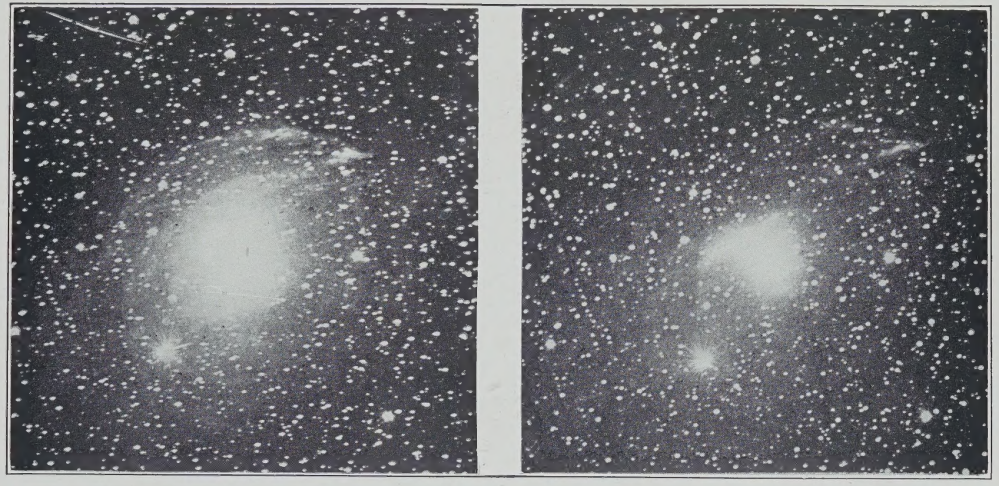
nine and a half magnitudes. After February 23rd the light curve made a slow, regular descent for about three weeks, while on March 19th, its light diminished by one and a half magnitudes. During the month of April a number of light fluctuations with short maxima and minima took place. These variations continued more or less during May and June, until in August they were detected with difficulty.

Along with the fluctuations of light there were colour changes. At the beginning the colour was white or bluish-white. In its descent it underwent various changes of colour, such as yellow, orange, light-red to dark-red. These are supposed to be the classes of colour exhibited by a body while it is cooling off from an excessive heat. During the time of its greatest fluctuations in the months of March and April, the colour of the Nova also fluctuated between whitish yellow and dull red. At minimum brightness it was dull red; while at maximum brightness its colour was white or yellow. As the light-changes became more constant, its colour assumed a greenish tint.

In observing the Nova with the spectroscope, the spectrum was found to be similar to that of Nova Aurigae. It showed a continuous spectrum of the solar type with dark lines, and superimposed upon that a gaseous spectrum with broad bright lines of hydrogen and other gases. As the Nova declined in brightness the dark lines disappeared in the spectrum, denoting that the cooler gases were absorbing a portion of the light and were succeeded by dark bands. It was found, indeed, that the spectrum of the Nova changed into that of a nebula. Further observation has led to the interesting discovery, that all those Novae which have been examined by the spectroscope, have actually become planetary nebulae.

On September 20th, Professor G. W. Ritchey of the Yerkes Observatory, was successful in taking a photograph of a very faint nebula encircling the Nova, having an apparent diameter of fifteen minutes

PLATE X. *to face page* 178.



NOVA PERSEI. CHANGED INTO PLANETARY NEBULA.
7 hrs. 19 mins. exposure. 7 hrs. 15 mins. exposure.

From a photograph taken at Harvard College Observatory.

of arc, or half the size of the full moon. This nebula was found to be almost circular, with the star in its centre.

In estimating the distance of Nova Persei, the generally accepted figure is 300 light years. If this estimate be correct, then the outburst of the Nova really happened about twelve years before the battle of Flodden took place, and the intelligence of the outbreak, (notwithstanding a light velocity of 186 thousand miles per second) only reached us in the year 1901. This Nova is still visible to us as a faint telescopic nebulous star of the 14th magnitude.

In the end of December 1910, another Nova suddenly made its appearance. On the evening of December 30th, when the Rev. T. E. Espin, of Durham, was observing stars in the constellation Lacerta and its surroundings, a red star, not recorded before, was detected by him near the boundary line of Lacerta towards the constellation Cepheus, situated in the Milky Way, the region where most of the Novae have been discovered. Professor Barnard maintained that the Nova was visible on photographs taken by him as far back as October 11th, 1893. Photographs taken by Professor Wolf on January 9th, 1894, also showed the Nova. It was then of the 13th magnitude. On January 10th its brightness rose to the 8th magnitude. The hydrogen lines in the spectrum became gradually fainter. After the middle of that month its luminosity diminished steadily to a star of the 10th magnitude, and the spectrum changed to the nebular condition.

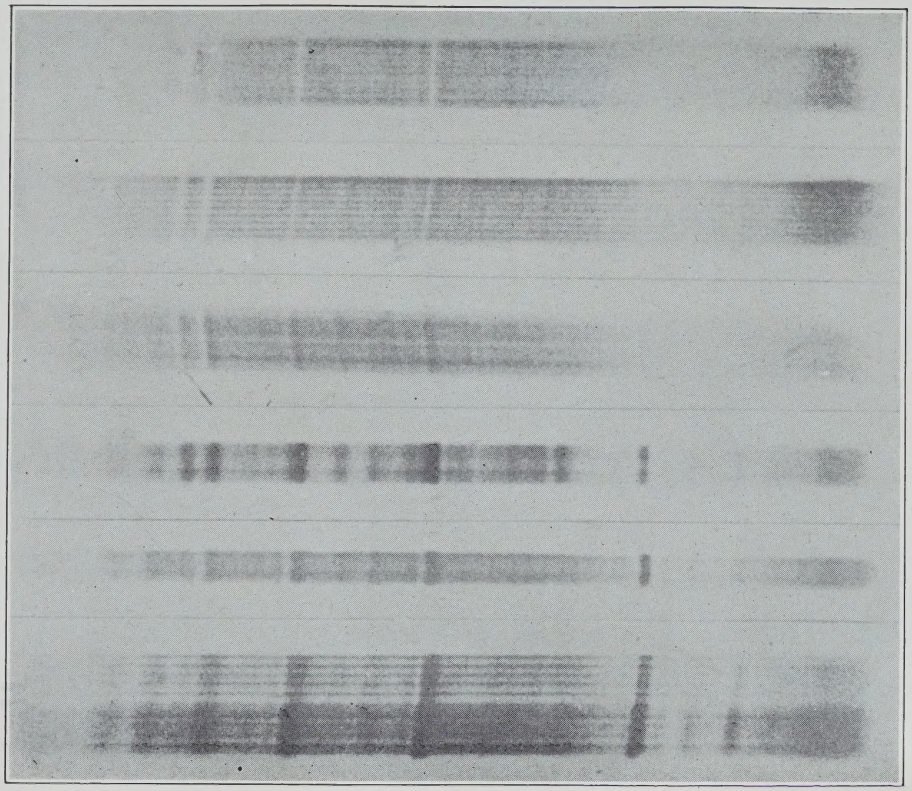
On March 12th, 1912, a Nova of the 4th magnitude suddenly burst forth in the constellation Gemini, and was first discovered by Herr Enebo at Dombaas, Norway.

An examination of the photographs of the Harvard College Observatory, showed no appearance of it on March 10th, notwithstanding stars appearing as faint as the 11th magnitude. A photograph taken the following evening, showed the Nova as a star of magnitude 4.5. From this we conclude that the star

appeared within twenty-four hours, and that during this interval, the light increased at least two hundred-fold. Three days afterwards, it was observed to fall rapidly in brightness; but on the 16th and 17th its decline was rather slow. On the 18th its light began to fluctuate, and on 19th and 20th it appeared as a star of magnitude 5.7. During the month of April its brightness fell quickly, and on May 11th, its magnitude was 7.3. A number of photographs of the spectrum of the Nova were obtained on March 13th. On that date, the spectrum resembled that of the Sun, the only difference being, that the hydrogen lines were stronger. It appeared therefore to belong to class F 5. Spectra of Nova Geminorum on four separate dates are shown on the plate. The first spectrum is that of Alpha Canis Minoris (Procyon) which is given here for purposes of comparison.

In the second spectrum, the dark line or band near λ 4739 is present in the Nova spectrum, while it is absent in Procyon. Lines near 4175 are also stronger in the Nova. In the third spectrum the dark lines $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$ and the calcium line K have broad, bright bands on the border of greater wave length. Other bright bands or spaces appear, three of which are apparent between $H\gamma$ and $H\delta$. The bright lines 4922 and 5016 are also seen. In the fourth spectrum the dark lines H and K have become fainter, and the maximum intensity of the bright lines $H\beta$, $H\gamma$, $H\delta$ has shifted towards the border of greater wave length. In the fifth spectrum, March 22nd, the dark hydrogen lines coinciding with the bright bands appear with marked intensity, and are apparent from $H\beta$ to $H\theta$ inclusive. The bright calcium band K has now disappeared, and only a dark narrow line remains. The sixth and last spectrum is that of Nova Persei, March 7th, which is shown on the plate for purposes of comparison with the spectra of Nova Geminorum. Several attempts have been made to measure its parallax, and it has been found to have an estimated distance of 296 light years.

PLATE XI. *to face page* 180.



SPECTRA NOVA GEMINORUM No. 2.

From a photograph taken at Harvard College Observatory.

One of the most brilliant of Novae was that which became quite visible to the naked eye on the evening of June 8th 1918. It received more attention, both from the layman and the astronomer, than any other Nova recorded in history. On the evening of its discovery it was as bright as the 1st magnitude star, Procyon, in Canis Minor. On the following evening, its luminosity rose five-fold, and it appeared twice as bright as Vega. Maximum brightness was reached between eleven o'clock that evening and three o'clock the following morning. On Monday June 10th, it was slightly brighter than Altair, but not so bright as Vega. On Thursday June 13th, it was as bright as Altair ; while on Sunday 16th at midnight, it was equal to Polaris in luminosity. After the first week its brightness slowly declined, and by the 20th it was below the 2nd magnitude. As it was in the constellation Aquila, nearly on the celestial equator and fifteen degrees south and west of Altair, it was well placed for observation. On June 29th its brightness fell rather quickly to magnitude 3.8. During the month of August it fell again to the 4th magnitude, its light variation seeming to coincide with that of Nova Persei in 1901.

The previous history of this star is registered in the library of photographs in Harvard College Observatory. Some of the photographic plates taken between the years 1888 and 1918 show it as a star of the 11th magnitude, while others show small fluctuations in brightness. On June 3rd 1918, its luminosity was quite normal. On the evening of the 6th it appeared as a star of the 6th magnitude, or one hundred times brighter than at normal; while on the 8th it was one of the brightest stars in the heavens.

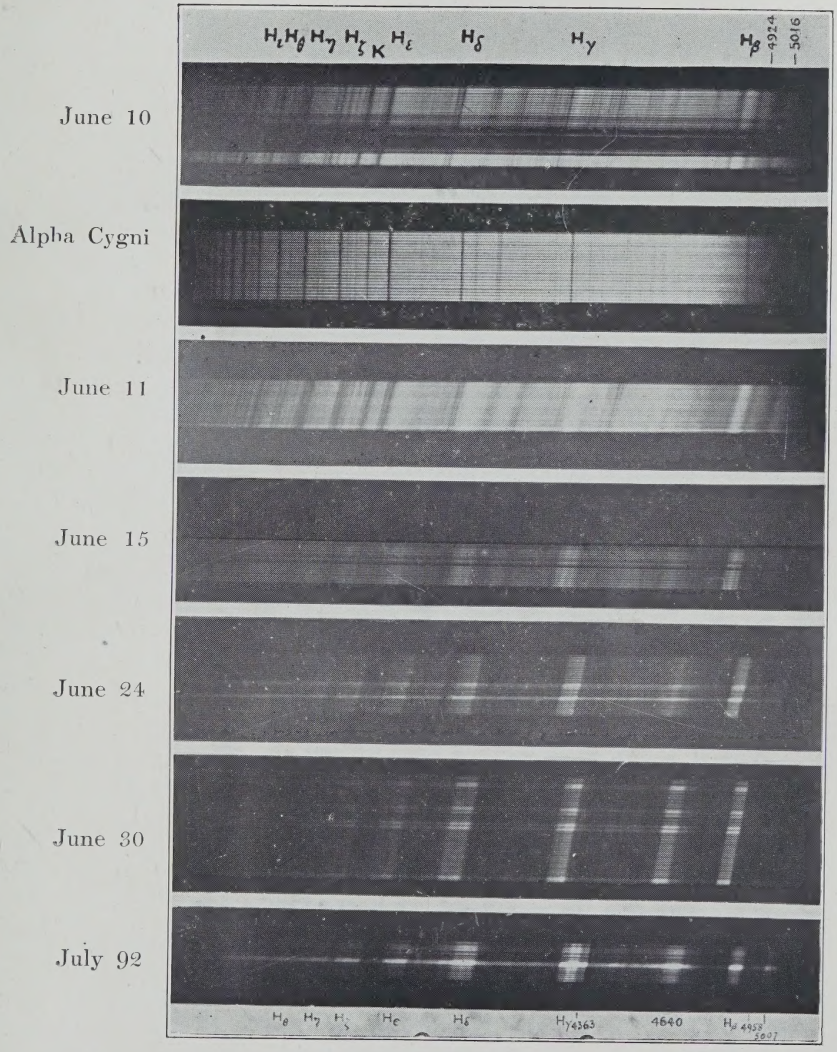
Shortly before it attained maximum brightness, its colour was bluish-while like Vega, with narrow dark lines of hydrogen. Three days after its discovery its colour changed to yellow, while from June until the end of that month its tint was red. In the beginning of August the red and yellow lines became less conspicuous.

Spectroscopic observations showed the spectrum to be similar to that of Nova Persei. The spectrum comprises all the hydrogen line series from $H\beta$ to $H\chi$ and consists of a series of dark lines similar to those of Alpha Cygni, and of a series of bright bands which, as in all novae, are in close proximity to the dark lines. These bright bands are also due to hydrogen. The distinction between the bright bands and the dark lines, is probably to be accounted for by the fact that the latter are due to the absorption of out-rushing gases and vapours, as they are all displaced to the violet end of the spectrum. On June 10th the bright bands were annexed to the hydrogen lines, more particularly $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$. The helium lines 4924, 5016, were blended with the enhanced iron lines. The bright hydrogen bands became more conspicuous on June 11th, 15th, 24th, 30th, and July 29th, when the dark line spectrum was disappearing. There was also a prominent narrow band between H and K calcium. There were two bright bands about 4640N. The nebular lines 4363, 4958, 5007 were also conspicuous. In March 1919 the Nova appeared as a star of the sixth magnitude, and five months later it was seen to have developed into a planetary nebula.

The last Nova was discovered by the astronomer, W. F. Denning of Bristol, in the constellation Cygnus, on the evening of August 20th 1920. At the time of discovery it was of magnitude 3.5. On 22nd its magnitude was 2.8. The star increased in brightness until the evening of the 24th, when it attained its maximum brightness of 1.8. After that date it fell away rapidly in intensity. The magnitudes of the Nova on August 31st and September 30th were 4.2 and 7.9 respectively. It is now below magnitude 9.

On August 23rd the spectrum was marked by dark lines due to hydrogen, calcium, and the lines of the enhanced spectrum of iron displaced towards the violet. This generally happens in the spectra of all Novae. There were also observed, undisplaced fine lines of calcium and sodium. The spectrum appeared to be

PLATE XII. *to face page* 182.



PROGRESSIVE SPECTRA OF NOVA AQUILÆ.

Stonyhurst College Observatory.

similar to that of Alpha Cygni, and was classed as belonging to type A.

Father Cortie, in an attractive article on Novae, which appeared in "Science Progress" Number 60, page, 618, says—"This spectrum substantially matches that of the star Alpha Cygni. Now the spectrum of Alpha Cygni is very similar to that which is not infrequently observed in outbursts of metallic vapours and gases on the Sun's surface in the neighbourhood of sun-spots. Such outbursts are indicative of an eruptive release of immense stores of internal energy. The sudden appearance of new stars, their rapid rise to luminous maximum, and the metallic vapours involved in the early spectrum, are all analogous to a cataclysmic eruption, though on a greatly enhanced scale, on the solar surface."

On the evening of the 22nd, dark lines were conspicuous at $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$. On the 25th there was an indication of broad bright hydrogen bands at $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, also H and K calcium. On the 26th, the bright lines were still more in evidence relative to the continuous spectrum. On the 27th the spectrum exhibited bright bands, interspersed with broad absorption lines superposed on a moderately strong continuous spectrum. On September 6th the bright bands, in addition to the hydrogen, were composed of the enhanced lines of iron, titanium, strontium, calcium, magnesium, and three lines of helium, while on September 11th, the helium lines were increased in number. On October 24th it was apparent that the nebular stage had commenced, for the nebular lines 4959 and 5007 were present, the latter being the stronger of the two. On June 3rd, 1905, a plate, taken at Heidelberg, shows stars of magnitude 16, but there was no appearance of the Nova. The last photograph of the region obtained there before the rise, is a plate taken on July 20th when the Nova was of magnitude 11. On August 19th it was of magnitude 4.8, while on August 20th it was of magnitude 3.5. From recent photographs of the spectrum

which have been taken, there is every indication that it has now assumed the form of a typical planetary nebula.

We shall now in closing, consider briefly the cause of these unexpected outbursts. Are we to understand that these Novae are new stars created to take the place of old ones; or are they suns which have, hundreds of millions of years ago, lost their powers of radiation as light-givers, but have become revivified owing to their shrunken crust breaking up and its liquid material suddenly bursting forth? This is a problem which cannot be satisfactorily solved.

Several theories have been proposed to explain the cause. One explanation is that the sudden appearance is caused by two suns colliding, which were, countless ages ago, intensely burning; but have become black and frigid. Were this to take place, it is absolutely certain that two huge globes, colliding with the immense velocity of 400 or 500 miles per second, produced by their mutual attraction, would be transmuted into a mass with such an enormous heat as would convert all the constituent matter into vapour. Such a violent impact would inevitably burst to pieces the suns' crusts, and set free all gases from the interior which had for ages been sealed up with all their properties intact.

A second theory is that of Sir Norman Lockyer. He assumes that two great swarms of meteoric particles, rushing in various courses, come into contact, and in doing so, they create very high temperatures and cause the different vapours to burn with fervent heat. This theory is objected to, owing to the fact that there is no proof of the existence of meteor streams of such enormous magnitude as would be necessary to cause an outburst large enough to be witnessed by us from a distance of 300 light years. Were this theory a correct one, these meteor streams would be able to produce only a faint glow.

The third and most popular explanation is, that the sudden outburst of light is produced by a star running

into a nebula or huge mass of nebulous matter. This theory meets most of the observed facts, and was first propounded by Dr. Seeliger. It is assumed that an extinct sun rushes into a nebula or cloud of dark material. Clouds of matter, faintly bright, are prevalent in certain portions of the heavens, and their size is so prodigious, that a dead sun, dashing with tremendous speed into one of these, would be much more likely to cause the phenomenon than two stars colliding with each other. Seeliger says "However rare the matter in the cloud may be, and whatever its physical condition, whether dust-like, liquid or gaseous, an intense, superficial heating of the visible body will result with the vaporization of its outer portions. These vaporized portions will, in part, soon detach themselves and rapidly assume the velocities of the portions of the cloud through which they are moving. We shall therefore obtain two spectra lying upon one another, one due to the incandescent body being continuous, and crossed by dark bands caused by absorbing vapours surrounding it; while the other spectrum will chiefly consist of bright lines. The two spectra will be relatively displaced in proportion to the relative velocities in the line of sight. It is not necessary to assume that the original relative velocities of the cosmical cloud and the dark star were very large. As the star approached the cloud, the latter would extend out to meet it, the relative velocities of the individual cloud-particles in the direction toward the star thus rapidly increasing as the two bodies came into near proximity. Supposing that the cloud is so constituted that its particles become chiefly subject to the action of the entering body, they will then describe hyperbolas about it as a focus, and will, accordingly, have very different velocities among themselves, so that their bright lines will be broad, diffuse, and liable to any of the peculiarities actually displayed in the spectrum of Nova Aurigae. As long as the body remains within the cloud, variations in its brightness and in its spectroscopic condition would repeatedly occur; but the

decline of its brightness would naturally be slow, until it emerged from the cloud, and thereafter rapid, which would agree with the observed facts."

This theory of Seeliger's explains the principal points of the phenomenon. There is every reason to believe that nebulous material is travelling in huge streams through space. Occasionally, streams of dark nebulous fluid may come under the powerful attraction of a star, and be pulled into it by the force of gravity. It has been computed that material attracted from an enormous distance into our Sun, would attain, on striking the photosphere of the Sun, a speed of 386 miles per second. The meteors which come into contact with our atmosphere have an average speed of about thirty miles per second. The friction of the atmosphere caused by this velocity, forces the meteor to burn up and be dissipated within three seconds of time. A huge meteor may retain its light for five or six seconds. The heat thus produced, is imparted to the Earth's atmosphere.

If we, therefore, imagine a huge stream of nebulous matter rushing through space towards our Solar System, we have a faint idea of what might take place, were a star in space, similar in size to our own, to come into collision with a nebula. An extinct sun might, in this way, have its atmosphere made intensely hot, and its surface transformed from a solid into a liquid condition.

As to the time when these cataclysms took place, which have resulted in visible spots of illumination in the heavens, we are not to imagine that the Novae burst forth on the same evening on which they happened to be discovered. The light from these stars which observers beheld for the first time with the naked eye, was speeding swiftly towards us probably for hundreds of years prior to visibility at the rate of 186,330 miles per second.

And so the assertion with which we set out as to the fascination and importance of those apparently fleeting centres of light, which emerge suddenly from the

depths of space and pass slowly beyond our ken, is amply borne out by the facts.

To see one of these apparently insignificant Novae sparkling in the sky, suggests to us not only vast cosmical cataclysms beyond all human comprehension in magnitude and force; but reminds us that we may be far-off witnesses of a process of development whereby the infinite God calls into being a new series of factors destined ultimately to result in a new solar system, similar, possibly to our own, whose components may, in the course of untold ages, become the abodes of beings just such as we are, and objects of the same divine love and care.

LECTURE IX.

Star Clusters.

Star clusters, and more especially globular clusters, in which thousands of stars are assembled closely together in a dense mass, are among the most wonderful and magnificent sights that the telescope discloses to us.

Very little information could be obtained about the clusters, until Sir William Herschel commenced in the year 1786 to study the sky with his great reflector. Later on, Sir John Herschel entered upon the work which his father laid down, and took a keen interest in the various classes of clusters seen in the southern hemisphere, but with the limitations of the instruments at his disposal his discoveries were necessarily circumscribed. In recent years, however, we have attained, by means of the present-day giant telescopes, a knowledge of clusters hitherto unknown, and some of the most eminent astronomers have been able to ascertain fairly well, the distances of a certain number of them.

In this lecture we shall consider the clusters under three divisions. First, irregular clusters; second, nebulous clusters; and third, globular clusters.

I. irregular clusters.

Irregular clusters assume no definite regular shape. The telescope reveals only faint signs of internal compression taking place in them; while they appear to be formed from star-streams.

A little to the north-west of Eta Geminorum is a fine region of telescopic stars, ranging from the

9th to the 16th magnitude. No less than 620 have been counted in the cluster within a circle of 26 minutes of arc in diameter. Notwithstanding this large number, photographs show that the stars are not nearly so numerous as those seen in photographs of globular clusters. This small cluster in Gemini looks to the naked eye like a nebula. Webb mentions that Lalande, in observing it, said :—"This is a marvellously striking object. No one can see it for the first time without an exclamation of wonder. The field of view is perfectly full of brilliant stars unusually equal in magnitude and in distribution over the whole area. Nothing but a sight of the object itself can convey an adequate idea of its exquisite beauty."

A similar cluster is found in the constellation Auriga. It consists of yellow stars belonging to the solar type spectrum. The entire collection amounts to five hundred, ranging from the 10th to the 14th magnitude. It is supposed that the stars in this compact mass are nearly all at the same distance from us. If this supposition be correct, then their absolute brightness must vary to a considerable degree. We have here an indication of the fact that the apparent brightness of stars depends largely on their distance from our Solar System.

The star cluster in Cassiopeia is a somewhat condensed mass of small stars from the 11th to the 18th magnitude.

There is a notable star cluster in the constellation Antinous, faintly visible to the naked eye, in the southern portion of Aquila. Sir William Herschel with his large reflector detected in this cluster, stars of the 11th magnitude. A photographic plate, recently taken, exhibits one thousand two hundred stars. Of that number, one-third are binary and multiple systems, while others are variable in their light.

The Praesepe of the ancients, called also the "Beehive," in the constellation Cancer, is an attractive

object in the heavens. Galileo with his rudely constructed telescope counted thirty-six stars in it. The late Professor E. C. Pickering and his assistants have photographed the spectra of ninety suns in that interesting group. They range in magnitude from 6.5 to 9.5; but owing to their faint appearance the particulars of their classification are not known. It has, however, been discovered that the collection is of a mixed nature. Of the ninety stars registered in the cluster twenty-eight have been found to belong to the A or Sirian type, sixty-one to the Solar type, while only one is known to belong to the third or M type. It is thus apparent that nearly one-third of the stars in the Praesepe cluster belong to the Sirian type of Spectra. The distance of this assemblage of stars in light years has not been ascertained, but it is assumed that it is nearer our Solar system than any of the globular clusters.

HYADES GROUP.

One of the most gorgeous irregular clusters is the Hyades, in the constellation Taurus. It is a particularly beautiful object in the heavens, and has been well-known for centuries, but in recent years it has received special attention, because it has been placed among the number of what are called "Moving Clusters." These are so named because they are star groups travelling towards a common region in the heavens at an equal velocity along parallel paths, and belonging to the same type of stellar spectra. The paths, though really parallel, appear (through perspective) to converge to, or diverge from a point. They seem to be physically connected much in the same way as binary systems. Notwithstanding the fact that many of the stars in the clusters are far apart from each other, their physical connection is proved by their corresponding motions. It has been found, however, that the ruddy star Aldebaran in the neighbourhood of the Hyades group, is not moving with that cluster, but that all the others have the

NEBULOSITY IN THE PLEIADES. Exposure 3 hrs. 30 mins.
Photograph taken with the 40 inch telescope at Yerkes Observatory.

PRAESEPE IN CANCER. Exposure 3 hrs. 8 mins.
Photographed by Professor Barnard at Yerkes Observatory.

same common motion toward a point a little to the east of Betelgeuse. This particular group measures fifteen degrees square, and contains 39 stars, one half of which are found to be binaries. It is supposed that a number of small telescopic stars within that area, partake of the same common motion.

Professor Campbell in his "Stellar Motions" says:— "The stars at their present distances from us are ranked as of the 3rd to the 7th magnitudes. In the distant future, after sixty-five millions of years elapse, this cluster, now fifteen degrees in diameter, will have condensed into a cluster not over one-third of a degree in diameter, with the stars reduced to the 9th and 12th magnitudes."

Some years ago, Professor Kapteyn ascertained the parallax of this collection of stars, and found that the centre of it is thirty times more distant from us than Alpha Centauri. This means that it takes light 131 years to travel from the centre of the cluster to our Solar System. As to the diameter of the cluster, it takes light fifty-four years to cross the distance. At the Yerkes Observatory, Chicago, it has been discovered, not only that the stars in the group have velocities ranging from twenty-five to thirty miles per second; but also that they are receding from our system.

Of the thirty-nine stars in the cluster, fourteen have been classed as stars of the 5th magnitude; while about twenty others have been found to be spectroscopic binary systems. Professor Eddington in his book "Stellar Movements," says regarding the stars in this group, "It appears that the thirty-nine are all much brighter bodies than the Sun. Five of the stars are from five to ten times more luminous than the Sun; eighteen of them are from ten to twenty times; eleven of them are from twenty to fifty times; and five of them are from fifty to one hundred times. In the vicinity of the Sun we have nothing to compare with this collection of magnificent orbs."

These figures give us a faint conception of the

immensity of this glorious cluster and the space which it occupies in the stellar universe.

In the "Sword-hand" of Perseus there are two very fine moving clusters. The stars in the upper collection have slow motions of less that 1.5 seconds of arc in 100 years. It is generally agreed that they are situated at enormous distances from us, and are physically connected with each other. In the lower group there are seventeen stars, and it is found that they are all moving together in the same direction. It is interesting to note that Alpha Persei of magnitude 1.7 partakes of the common movement.

There are two other moving clusters which are worthy of passing mention. The first is in the constellation Cygnus. It has an actual motion of fifty miles per second, and includes in it the binary star 61 Cygni. The second is in Scorpio. The brightest of the group is the ruddy star Antares whose spectrum belongs to type M. Excepting this star, which is a giant in size, all the others are probably miniature suns.

The most interesting of all stellar groups, however, is that in Ursa Major, consisting of the familiar stars Beta, Gamma, Delta, Epsilon, and Zeta. It has been discovered that all these five stars have a close relation to each other. Notwithstanding the fact that each of them is much further apart than those in the Hyades, there is ample evidence to show that they are all under the control of the same general motion, and have an equal speed along parallel lines. The only difference between the group and the Hyades is, that the former are moving towards a common point in the opposite part of the sky. Alpha and Eta, it should be noted, however, are found to be moving at the same rate, but on other parallel paths. The late Sir William Huggins, the eminent English spectroscopist, found by means of the spectroscope, that all these stars were travelling in the same direction with almost equal speed, and receding from our system with a velocity of twenty miles per second. We have here convincing

evidence that these five stars form a connected system. The English astronomer, the late R. A. Proctor, alluded to them as "drifting stars," and this general motion along parallel paths, where stellar clusters seem to be moving as connected systems, he called "star drift." It is a most wonderful thing and a most staggering conception to think that those five giant suns, each one separated from the other by at least ten light years, should be moving at the same velocity along parallel paths in one magnificent procession towards an unknown region of the heavens.

The other two bright stars in the constellation, Alpha and Eta, which form one system distinct from the other five, are twenty degrees apart. This means that they are at least thirty light years distant from each other. All those stars have a common proper motion of Right Ascension of nearly eight seconds of arc in 100 years. They are all in the early stages of stellar evolution, and most of them form binary systems. Professor Campbell, in his "Stellar Motions," says "They are all exceedingly brilliant suns. Their luminosities are to that of our Sun in the following ratio: Alpha 126, Beta 72, Gamma 66, Delta 32, Epsilon 105, Zeta 87, Eta 95."

One of the most interesting facts connected with this Ursa Major stream is, that it includes, in distant parts of the sky, the well-known stars, Sirius, Beta Aurigae, Beta Eridani, Delta Leonis, Alpha Coronae, 1930 Groombridge, 37 and 78 Ursae Majoris. It is interesting also to note that Beta Aurigae emits more light than all the other seven combined. Its luminosity is computed to be 410 times that of our Sun.

Melotte of Greenwich Observatory formed an interesting catalogue of star clusters which he divided into four groups. The first numbers eighty-three globular clusters, in which the stars are condensed towards the centre. The second containing ninety-three, is composed of loose clusters which have well-defined outlines. The third numbers ninety-five. It consists of loose clusters with irregular outlines; while the

fourth numbering fourteen comprises large clusters such as the Hyades and Pleiades. He enumerates in all, 245 clusters; all of which are at enormous distances from us, but are nevertheless members of our own stellar universe. In the first group, most of the globular clusters are less than five minutes of arc in diameter, twenty-two of them are between five and ten minutes of arc in diameter, while eleven of them are between ten and twenty minutes in diameter. The loose clusters comprising the second and third groups, which practically compose one class, are situated within thirty degrees of the Milky Way, while most of them are within twenty degrees of it. The actual distances of these irregular clusters have not yet been ascertained; but all astronomers acknowledge that they are much nearer our solar system than the globular clusters are, possibly five thousand light years.

II. NEBULOUS STAR CLUSTERS.

We come now to treat of nebulous clusters. This class appears generally to be immersed in a mass of nebulous matter; hence the name.

The nebulous cluster in the Constellation Sagittarius, has both the appearance of a cluster and a nebula. On a fine, moonless evening it is faintly visible to the naked eye. Its diameter east and west is forty-five minutes of arc, while its diameter north and south is forty-two minutes. A number of the stars seem to be merged in nebulosity.

Another nebulous cluster is in the Constellation Monoceros. Sir John Herschel was the first to detect it. It is about one degree in diameter, and its brightness and outline are irregular. It is of interest, because a star has been discovered in it, named 15 Monocerotis. It is surrounded with nebulosity, and is found to be both a variable and a ternary system. The companions are separated from the primary by 2.8 and 16.6 seconds of arc. The light of the primary varies in magnitude from 4.9 to 5.4 in

a period of three and a half days. In the cluster, between fifty and sixty stars have been counted, ranging from the 8th to the 13th magnitude.

The typical cluster of this nebulous class and another instance of a moving cluster is the Pleiades. Six stars in this collection can readily be seen with the naked eye on a clear evening. Those who have good eyesight can pick up seven or nine. The cluster of bright stars is one degree in length east and west, and two-thirds of a degree in breadth. Within a radius of five degrees there is only one star of the 5th magnitude, while there are only ten of the 6th. When a small telescope, however, is fixed upon this cluster, a great number of glowing suns is disclosed to view. It is then seen that the collection is a real stellar cluster, the whole field of vision being actually scattered with sparkling points of light of various degrees of magnitude. With the aid of a three inch refractor, as many as eighty or ninety stars can be counted down to the 9th magnitude.

The best and most precise way of counting the stars in any particular region of the sky is, by securing the images on a photographic plate. Professor Bailey of Harvard College Observatory, made a count of all the stars upon a negative exposed to the Pleiades group, and found nearly 4000 within a small area of only two degrees square, with Alcyone, the lucida of the cluster, in the centre. The faintest stars recorded on the photographic chart, are of the 17th magnitude. Taking Alcyone as a star of the 3rd magnitude there is a difference of fourteen magnitudes between it and these other stars. This difference in light ratio means, that Alcyone is at least a thousand times brighter than the faintest stars in the cluster.

Some years ago Professor H. C. Wilson made a count of the stars in the same cluster from several long exposure photographic plates, and found on one which had an exposure of seven hours in a region of two degrees, more than 3000 stars. While on another photographic plate which had an exposure of sixteen

hours to the same region, he counted about 4500 stars. As an illustration of what astronomy has gained from its alliance with photography, it is interesting to note that within that small boundary of only two degrees square, there are more stars than are to be seen with the naked eye over the whole northern sky. We are not to infer from this large count, however, that all those glittering points of light are physically connected with the Pleiades cluster. It is very likely that most of them are situated at enormous distances beyond it.

In recent years, repeated measurements have been made of more than sixty stars in the group down to the 9th magnitude, and it has been found that they all have, along with Alcyone, a common proper motion, and are moving through space at a regular speed of nearly six seconds of arc in a century. All these stars thus constitute a veritable cluster at nearly the same distance from our solar system.

There are only six stars in the collection that are brighter than the 5th magnitude. The apparent distance between the two furthest apart of these six stars is one degree. It would take light twelve years to cross the distance. The diameter of the whole cluster is calculated to be about seventy light years. Its parallax is so small, that it takes light 260 years to reach us. Corresponding with this distance, Alcyone, the brightest unit, must emit at least 300 times more light than our Sun, while the light-giving power of the six bright stars must be, on the average, 100 times greater than that of our solar light.

From these figures, we conclude that those stars are giants compared with ours. The brightest stars in the cluster exhibit a spectrum midway between B and A types. Photographic plates show that they are surrounded by a mass of this nebulous matter. Some of them are involved in nebulosity more than others. From this, we infer that the surrounding medium is the remnant of the nebulous matter from which the stars were formed.

With the aid of a field glass, the brightest stars can

easily be picked up. Alcyone is situated in the centre of the group. Atlas lies to the left; Pleione is above; Electra lies to the right; Merope is situated below and is immersed in a mass of nebulosity; while Maia lies above and is also enclosed in nebulous matter.

It is worthy of mention that two of these stars which are enveloped in nebulosity, namely, Merope and Maia, are classed as Orion or helium stars, that is, they are stars in whose spectrum the lines of helium are strongly in evidence. They belong to B type, and, according to the Giant and Dwarf hypothesis, they must be regarded as being in their prime of life. There are four stars of smaller magnitude which are situated near Maia to the west and north. These are Celoena, Taygeta, Asterope, (1) and Asterope (2).

The faint stars do not seem to be equally divided in and around the cluster. They appear to be scattered in larger numbers on the eastern part than on the western. In the southern portion of Merope, the space seems to be practically blank. It is a very remarkable fact, that towards the north-east, or Milky Way, there is a decided increase in the number of stars, while towards the south and west there is a decrease. The only way in which we can account for this decrease is, that the nebulous matter must be interrupting our view of the fainter stars that are more distant from our Solar System than the nebulosity itself. From these facts, we are thus confronted with the startling fact, as Professor Barnard calls it, "that the Pleiades and their involved nebulosities are but the central condensations of an enormous nebula, intricate in details, and covering at least one hundred square degrees of the sky."

III. GLOBULAR STAR CLUSTERS.

We come now to consider the Globular star clusters, the most remote objects in our own stellar universe. More than 200 of these remarkable objects have been registered in the general catalogue. I shall mention some of the most notable, and begin with two of the

most conspicuous in the southern hemisphere, viz., Omega Centauri and 47 Toucani. Omega Centauri is said to be a truly gorgeous globular cluster, the most beautiful in the sky and quite visible to the naked eye. Indeed, as will be seen from the quotations to be given regarding these clusters in the southern hemisphere, astronomers appear to be unable to use anything but superlatives to describe them. Sir John Herschel, in speaking of Omega Centauri, refers to it as "the richest and largest object of its kind in the heavens. The stars," he says, "are literally innumerable, all clearly resolved into stars of two magnitudes, viz., 13th and 15th." A photograph was taken of this marvellous cluster by Professor Bailey, and on the photographic plate he counted nearly 6,500 separate suns. The late Professor E. C. Pickering, however, was of the opinion that some of these stars were altogether disconnected with the cluster, and that the real number was about 5,000. Of that number, Professor Bailey discovered 132 variable stars from the 10th to the 14th magnitude.

The second in excellence to Omega Centauri is 47 Toucani. Sir John Herschel describes it in the following terms: "A most magnificent globular cluster. It fills the field with its outskirts. The stars are of the 14th magnitude and are immensely numerous and compressed." Dr. Gould named it "one of the most impressive and perhaps the grandest of its kind in either hemisphere." According to Professor Bailey, who photographed the cluster, the number of stars it contains is about 1,500. Among these he found three variable stars, and since then, others have been discovered. Professor Harlow Shapley estimates the distance of these two clusters to be about 22,000 light years.

Half-way between Alpha and Beta Scorpii there is a condensed globular cluster of stars of the 14th magnitude. Sir William Herschel called it "the richest and most condensed mass of stars in the heavens," and spoke of it as "on the western edge of a

CLUSTER IN HERCULES.
Photograph taken by Professor Plaskett, Director of Victoria Observatory, B. C.

CLUSTER M3.
CANES VENATICI. Exposure 6 hrs.
Photographed by Professor Ritchey.

CLUSTER.
47 TOUCANI. Exposure 4 hrs.
Photograph taken at Arequipa.

vast starless opening four degrees broad." It is inconceivable to suppose that the thousands of suns which seem to be here collected into one huge mass can be at rest, for their reciprocal attraction must create a certain amount of speed in each body. They must all be more or less in motion. Our imagination is staggered and our own insignificance becomes manifest when we contemplate the fact that each of these bright minute points is a hot, glowing sun flaming through space.

Another globular cluster is in the constellation Pegasus north-east of the star Delta Aquilae. Sir William Herschel resolved it into stars, while his son, Sir John, estimated their average magnitude to be 15. The late Dr. Roberts photographed the cluster and counted 900 stars, of which 51 have been found to be variable.

In the constellation Libra, there is a beautiful cluster of stars ranging from the 11th to the 15th magnitude, which is compressed in the centre. Professor Bailey recently determined the variation periods and light curves of about 70 variables in this cluster of 750 stars. He discovered three of them to have periods longer than one day.

One of the most notable of globular clusters, in our northern hemisphere is close to the southern edge of Canes Venatici about twelve degrees north-west of Arcturus. Professor Harlow Shapley, Director of the Harvard College Observatory, calculates its diameter at 30,000,000 astronomical units. This means that light requires 470 years to travel from one end of the cluster to the other. Within the cluster there are at least 1,800 suns. The brightest are supposed to emit 2,000 times more light than the Sun and are comparable with Rigel and Canopus. A photographic plate taken at the Lick Observatory shows stars from the 11th to the 20th magnitude. Professor Shapley estimates the distance from this cluster at nearly 3,000,000,000 times the Sun's distance from the Earth. This means that the light which we see from

that cluster now, left it 44,000 years ago. Nearly 150 variable stars have been discovered in this group, some of which are lying in the centre of the cluster, while others are situated at greater distances.

The finest and brightest of all globular clusters in our northern sky is in the constellation Hercules on a line joining the 3rd magnitude stars, Eta and Zeta. Halley was the first to discover it in 1714. Sir William Herschel described it as "a most beautiful cluster of stars exceedingly compressed in the middle and very rich." When a large telescope is directed to this cluster, it is resolved into an immense number of stars. They have all an extremely faint appearance, but the assemblage of stars is so great, the whole field of view being thickly covered with glittering points of light, that the sight is a most impressive one.

Photographic plates which have been exposed for several hours at Mount Wilson, Lick, and Harvard Observatories, disclose a much larger number of units than is discerned through the telescope. In fact, as many as 50,000 separate suns down to the 20th magnitude have been estimated. The most condensed portion is in the centre, and the diameter of the cluster itself is fifteen minutes of arc. Professor Shapley estimates it would take light, with a velocity of 186,330 miles per second, 200 years to cross from one side of the cluster to the other.

The stars which appear to us as a compact mass, must be at least 25,000,000,000 miles apart, or five times the diameter of the Solar System. This is unquestionably one of the most wonderful clusters in the heavens, and is practically so to speak, a small universe in itself. These bright points which are thickly scattered over a small region of the sky are suns, some of them larger and others smaller than our own.

The question is sometimes asked, what purpose is being served in the creation of this vast number of suns? Webb has well remarked, "The mere aspect of this stupendous aggregation is indeed enough

to make the mind shrink with a sense of the insignificance of our little world. Yet the Christian will not forget that, as it has been nobly said, He took of the dust of this Earth and with it He rules the universe."

In this cluster we have different stages in the process of evolution. At Mount Wilson Observatory it was found that the spectra of many of the stars belong to different types. All those which were examined, were found to have spectra similar to those of suns in our own region of space. They vary in colour, just like those visible to the naked eye. Some of them are bluish-white like Sirius and Vega; while others are red like Arcturus and Aldebaran.

This cluster must be situated at a vast distance from us as is quite apparent from the fact that those huge suns which compose it, appear to us so inconspicuous. Sufficient data cannot be obtained as yet for an exact count, but it has been estimated by Professor Shapley, that they must be distant from us 35,000 light years, or two thousand million times the Sun's distance from the Earth. No apparent motion has been discovered among the stars of the cluster, even on photographic plates, during the past twenty years. Professor Barnard discovered two Cepheid variable stars in the cluster, while Professor Shapley found five, of which four have periods of less than one day.

METHOD EMPLOYED FOR ESTIMATING DISTANCES OF GLOBULAR CLUSTERS.

I shall try to describe briefly the method by which Professor Shapley estimated the distances of the globular clusters. This method is furnished by the uniformity in apparent magnitude in the variable stars which are found in any given cluster. For instance, the variable stars in the cluster Messier 3 have a mean magnitude 15.50, with an average deviation for individual stars not greater than 0.08 magnitude. When, therefore, in the cluster Omega Centauri, we find that the variable stars have an apparent magnitude

1.93 brighter than those in Messier 3, we may safely conclude that the difference in brightness is a criterion of the relative distances of the two clusters. A difference in apparent magnitude of 1.93 corresponds to a difference in distance of 2.4 since the intensity of illumination varies inversely as the square of the distance. That is, the variable stars in Messier 3 are 2.4 times more remote than those in Omega Centauri. Now to get their real distance, we must have recourse to variables in our own system of stars. Their apparent magnitudes are known, the distances of many of them are known, hence their absolute magnitudes are known from the relation already mentioned, which connects absolute magnitude with apparent magnitude and distance.

Also we must make the reasonable supposition that all such variables have the same absolute magnitude. Hence we know the absolute magnitude of the variables in the star clusters, and the apparent magnitudes being known, it is possible to deduce their parallaxes or distances.

In this connection we may instance as noteworthy examples the short period Cepheid variables. These stars are all, without exception, much more luminous than our Sun. Shapley finds, from a careful study of more than 200 of them, that their average luminosity depends on the period of variation. Cepheids, with a period of one day, are nearly 100 times brighter than the Sun. Those with a period of four days are 400 times brighter than the Sun ; while those with periods of ten days, are on the average, 1500 times brighter than the Sun. The longer their period, the more quickly their luminosity increases. Those variables which have the same period, are similar in brightness to each other.

Variables, notwithstanding their distance and feeble light, are known by their type of light change. Stars of this class, particularly short period ones, are found in the globular clusters. These are calculated to be 100 times brighter than the Sun. And as we have

seen, by measuring their luminosity, not only are their distances determined, but also the distance of the cluster to which they belong.

Regarding the clusters in general, Professor Shapley finds that in every cluster where variables are detected, the brightest stars in the clusters are, on an average, three times brighter on photographic plates than the variables. The greater number of these bright stars are red, and are consequently much brighter visually than photographically, so that if they are measured with the eye in the usual way, they would be, on the average, 1,000 times brighter that the Sun.

Drs. Russell and Hertzsprung have given this matter careful scrutiny, and have found that both the mass and luminosity of the star can be estimated from the variation of a star's light. By comparing the luminosity with which the star appears to us to shine with the calculated brightness which it would have if it were situated at some standard distance, the real distance of variable stars under observation can be determined. From their results, it was found that short period variables, such as Delta Cephei, were at least more than 200 light years distant from us. It was also found that nearly one-half of the eclipsing variables and three-fourths of the Cepheid variables are more than 2,000 light years distant; while others exceed that distance by 5,000 light years. By means of this method, the light distance of the stars has been determined to a high degree of accuracy.

Regarding the radial velocities of these globular clusters, Professor Slipher finds they are travelling at a much slower rate than the spiral nebulae. Their mean speed is about ninety miles per second. It has not been possible yet to compute the velocities of each of the stars in these clusters. If, as has been calculated, the fastest stars have a mean velocity of fifty miles per second, while the globular clusters have an average speed of ninety miles per second, and nebulae 240 miles per second, then we must infer that the velocities of the globular clusters are intermediate between the stars

and the spiral nebulae; and still further, we must conclude that the globular clusters are not external universes as the spiral nebulæ have, of late years, been assumed to be; but that they belong to our own universe.

It is appropriate here to mention the way in which globular clusters are arranged in space. It has long been a well known fact that they are not uniformly distributed over the sky; nor do they, like the majority of heavenly objects, congregate toward the plane of the Milky Way. They rather limit themselves to one-half of the heavenly sphere, with its centre in the constellation Scorpio, which contains more than sixty such clusters; while in the opposite half of the sky there are less than half a dozen. This proves, of course, that our Solar System is nowhere near the centre of the region of space within which these clusters are situated; but must be almost at its border. It was quite unknown how large this region is, and in what way the clusters are distributed within it, until Shapley began his research work.

These interesting and marvellous researches tend to prove that this arrangement of the positions of hundreds of millions of suns, clusters and nebulae which fill space, could not possibly happen without design. Gigantic as our Sun is, it is a somewhat disconcerting thing to think, that after all, it is just a common-place and almost invisible star as compared with the millions of others that sparkle in the sky above us.

It is also beyond the powers of human thought to conceive the further fact, that these huge suns are rushing through space with stupendous speed, many of them at the rate of 100 and 200 miles per second.

But the most baffling and incomprehensible of all problems, is the one that faces us when we try to imagine the inconceivable vastness of space through which they speed along in their orbits, under the force of that mystery which the human mind can define but cannot explain, gravitation. The space through which they rush in what, for all their incredible number and

apparent proximity, we can only describe as magnificent loneliness and isolation, this space is practically so infinite and immeasurable so far as our imagination can grasp it, that the distances apart of those individual, binary, and ternary systems, must be measured by billions of miles.

What can we say in view of all these facts, but that we have our part, incredibly small as it is, in a marvellous universe whose limits are boundless. Some further distance into the depths of infinite space we may be able to penetrate as "knowledge grows from more to more" and "the thoughts of men are widened with the process of the Suns"; but even when science has done its utmost with the most powerful aids to vision that we can conceive, there must still remain range upon range of God's infinite universe, which shall ever remain beyond the reach of our finite power, an unplumbed depth, at whose furthest known margin the mind and soul of man can only stand with reverence and adoring praise as at what may be after all, the mere gateway of the Father's Home.

LECTURE X.

The Nebulae.

We come to-day to the consideration of the closing subject of the present course of lectures, namely—the Nebulae. These are composed of marvellous masses of diffused gaseous matter outside of our own Solar System, and represent in themselves a universe so enormous in size, that our own Solar System, great as it seems to us, is only as a grain of sand in comparison with it. By turning our thoughts to these small patches of light in the heavens, we shall be able to acquire a faint conception of the boundless space of this external universe of stars.

It is comparatively easy for us to grasp the fact that the Earth's circumference is 25,000 miles, or that the Moon's distance is 240,000 miles; but it is difficult for us to believe that the Sun is 93,000,000 of miles away, or that the nearest star is four and one-third light years distant from us. More baffling than all these, however, is the attempt to conceive in any real sense, the significance of the stupendous figures we have to employ when we come to consider the distances of the nebulae from our own world. It is easy to say that some of these hazy spots of light in the heavens, represent a luminosity that left them for its long journey towards our Earth, thousands of years ago; but the human mind is utterly incapable of realising the meaning of such a statement. Yet the mere fact that we have been able to pierce so far into the profundities of space, opens up before us a subject of enthralling interest.

The nebulae are quite different in appearance and

form compared with the stars. Several of them can only be seen with the naked eye ; but when a telescope is directed upon them, they have the semblance of extremely faint, whitish clouds. That is why they have been called "nebulae" from the Latin word "nebula," a cloud. Their remarkable form is best seen, however, on photographic plates of seven or eight hours' exposure, taken with great reflecting telescopes. By means of photography, the number of nebulae has been increased to an astonishing extent, several hundred thousand having been discovered, ranging from two or three seconds to thirty minutes of arc in apparent diameter. This means that the actual diameters of many of them must be as far as Alpha Centauri is distant from our own Sun.

It is interesting to note the various stages of discovery by means of which our knowledge of those marvellous light clouds has been advanced. Messier was the first to publish a catalogue of nebulae and clusters. This appeared in the year 1748. About thirty years later Sir William Herschel commenced in earnest the observation of nebulae, and in twenty years time he was able to register 2,500. Sir John took up the work which his father laid down, and made a diligent scrutiny of the southern hemisphere by making observations at the Cape of Good Hope about the year 1830. Some years after this he made a chart of all the nebulae which he and his father had discovered. In the year 1845, it was found by means of the huge reflector belonging to Lord Rosse, that some of the nebulae had a spiral form. From this discovery it was concluded that they were swiftly rotating bodies.

In the year 1898 a great advance was made in this subject by Professor J. C. Keeler, with the giant reflecting telescope of the Lick Observatory. He took photographs of various regions of the heavens, and by this means he was able to register thousands of nebulæ which had not been discovered before. In studying these photographic plates, he found that most of the nebulae were really spirals in their nature. In recent

years Professor Fath, at the Mount Wilson Solar Observatory, made photographs of no less than 139 different portions of the heavens in the northern hemisphere, and by making a count of the number of nebulae found on those plates, he estimated that there must be at least 162,000 separate nebulae in the heavens.

All these nebulae have different shapes; but it will be advantageous for us to divide them into three principal groups.

I. THE LARGE NEBULAE OF IRREGULAR FORMS.

These are composed of huge, massive bodies of bright, gaseous material, resembling small clouds. They are usually to be seen in the Milky Way, or not very far from it, and in places where the stars are more abundantly situated. It is also noticeable that they are found amongst stars that have just developed from nebulosity, and appear to be moving at a very slow rate of speed. Professor Curtis regards them as "the primordial stuff from which stars are made, and are always connected with those classes of stars which are believed to be the youngest."

TRIFID NEBULA.

Of this group, one of the most notable is the Trifid Nebula in Sagittarius. When the spectroscope is directed upon this nebula, it is found that it is a gaseous body, composed chiefly of hydrogen, helium, and nebulium. The various gases which it contains, show that the nebula is in its earliest stages of evolution.

THE GREAT NEBULA OF ORION.

The Orion Nebula is one of the most wonderful objects in the heavens. Observations made with large telescopes show that its appearance is an unusual one compared with other nebulae of this class. To account for its peculiar form it has been suggested that a huge nebula may have run into another one, causing a tremendous upheaval of various gases, the remains or loose fragments of which are strewn in the background

GREAT SPIRAL NEBULA M 51 Canes Venatici.
Photograph taken at Lick Observatory.

ORION NEBULA.
Photographed by Professor Keeler, Lick Observatory.

of the thickest part of the nebula. The dark opening bearing a resemblance to the mouth of a fish, contains at least seven stars which have undoubtedly developed from the nebular matter. A dark lane, similar to that seen in the Trifid Nebula, is also in evidence, and appears to be in process of formation. Huyghens was the first to observe, in 1656, three stars in the small cluster, now familiarly known as the Trapezium. The fourth star was found some time after; while in later years, probably in the time of the Herschels, two of these four telescopic stars were found to have faint companions revolving round their primaries. Professor Barnard discovered, with the aid of the 36 inch Lick refractor, one or two very faint stars—the companions referred to—while Professors Frost and Adams, at the Yerkes Observatory, detected the further fact, that the brightest star in the Trapezium is a spectroscopic binary system.

This star cluster, named Theta Orionis, is truly one of the most fascinating and marvellous spectacles in the heavens, composing one physical stellar system of such enormous dimensions that, compared with it, our own Solar System is but an atom. A more marvellous thing, however, is the fleecy mass of greenish-white light which surrounds these stars. While it appears to the unaided eye as a small misty patch, a field glass shows the brighter portion fairly well; but to one who has a large telescope with a high magnifying power, it is revealed as a luminous cloud, and is of surpassing interest. By means of the spectroscope, it has been found that the nebula is composed of various gases shining by inherent light. Its apparent diameter measures two-thirds of a degree. The estimated distance of the nebula is 1600 light years.

This enormous mass of matter is, unquestionably, in a state of incandescence. Changes of an extraordinary nature must be going on perpetually in the entire extent of the nebula, but owing to its immense distance it is impossible for us to mark those changes. The process of stellar evolution is so incredibly slow

that it must require millions of years before any perceptible movement or transition from one stage to another can be detected. The actual motion of the nebula through space is comparatively slow, but its angular displacement is so extremely small per annum that it appears to us to be absolutely stationary. It has been discovered, however, by the spectroscope, that it is receding from us, at the rate of about twelve miles per second.

From recent investigations which have been made regarding the various gases contained in the nebula, it has been found that they are not in a state of rest. Several eminent scientists such as Buison, Fabry, and Bourget of Marseilles, have discovered that various portions of this gaseous nebula are in motion, and that each has a speed of its own. They also find that the atomic weights of the unknown gases to be found in it are intermediate between those of hydrogen and helium.

Other scientists have been successful in measuring the radial velocities of the gases in the nebula, and they have discovered that in some portions the gases are receding from us, while in others they are approaching us with a speed of seven miles per second.

In referring further to irregular nebulae there are two whose spectra correspond with the bright stars which appear to be involved in them. From this it has been concluded that the light proceeding from the two nebulae is not inherent, but is instead the light reflected from the bright stars which are surrounded by nebulosity.

The first is the nebulosity which encompasses the Pleiades group. The second is that which surrounds the star Rho Ophiuchi.

It is already well-known that the area around the Pleiades cluster is immersed in nebulosity. In consequence of this, many of the faint stars are invisible. In other words, the nebulosity in that region is interrupting the light which is being emitted from

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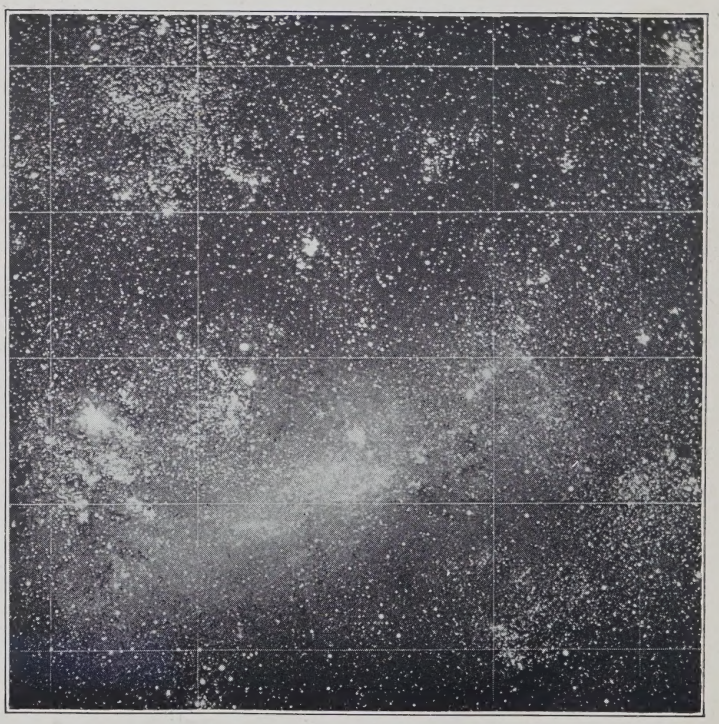
SOUTHERN CROSS AND COAL SACKS.



NUBECULA MAJOR.
(Larger Magellanic Cloud.)

these faint stars which are much more distant from us than the nebular matter. The same holds true in regard to the region of the sky near Rho Ophiuchi. The faint stars remain invisible to us in consequence of the nebulosity intercepting the light which comes from the stars situated at greater distances from us than the nebular matter.

COAL SACKS.

Near the Southern Cross there are two notable "black holes" named "Coal Sacks." In that region there is a large number of stars; but in two small regions there are apparently few or none. In fact the two areas are almost blank. The only explanation which can be given is, that there are, in reality, faint telescopic stars in these so called "black holes;" but it is impossible for the telescope to pierce through the nebulosity that exists between us and them. The nebular matter is obscuring the light which is being emitted from them.

II. THE SPIRALS.

Let us now consider the second class of nebulae, namely The Spirals. One of the most remarkable facts about spirals is, that they are seldom seen in the Milky Way. They seem rather to avoid this particular area, though they are usually found not far from its Poles where there is a scarcity of stars.

An interesting point worth while mentioning here in passing is, that spirals have a continuous spectrum, while the gaseous nebulae have a bright-line spectrum.

The speed of spirals through space is prodigious, being on the mean 500 miles per second. More than 200,000 of this group have now been recorded. Recently, however, Professor Curtis made a count of the small nebulae on all regions possible, taken at the Lick Observatory during the past twenty years; and, from these counts, he estimated that there are at least 700,000 spiral nebulae accessible with large reflectors.

From photographs taken of those spirals it has been found that various parts of them are moving at a great speed. The speeds of approach and recession of some of the spirals have been measured by Professor Slipher, and as the result of his spectroscopic observations he finds that, in some cases, they reach an enormous velocity of between 600 and 700 miles per second, while others have a speed of 250 miles per second. Not one of the so-called "runaway stars" has a velocity approaching to anything like this.

Professor Curtis late of Lick Observatory, and now Director of the Allegheny Observatory, has given considerable attention to the nebulae in general, and from the photographs which he has taken of the spiral nebulae for the past twenty years he finds that their motions in the sky are extremely small, not exceeding two or three seconds of arc in one hundred years. In consideration of this small angular measurement, it is doubtful if, in twenty years time, the slightest motion of any of the spirals could be observed. From this imperceptible motion we must infer that they are situated at immense distances from us, and are the most gigantic objects that move in space.

These interesting discoveries which have been made reveal to us the vast magnitudes of these objects. They are so enormously great, that if the centre of one was situated close to our Sun, its external parts would stretch far beyond the nearest stars all around the sky. The entire quantity of light which one of these spirals emits must be thousands of times greater than our Sun sends out. It is no exaggeration to say that the mass of material contained in any one of them must be proportionally large, in fact it has been computed that the entire mass of some of these individual nebulae would be sufficient to form millions of globes like the Sun. Professor Campbell says, "Some of the Spirals seem to contain enough material to make tens of thousands of stars comparable in mass with our own Sun."

NUBECULA MINOR. *(Smaller Magellanic Cloud.)*
Photographed at Arequipa. Exposure 4 hours.

GREAT SPIRAL NEBULA. M 33 in Triangulum. Exp. 3 hrs. 30 mins.
Photographed at Lick Observatory.

We shall now mention some of the most outstanding of the nebulae belonging to this class.

MESSIER 64 (FROM ITS NUMBER IN MESSIER'S CATALOGUE) COMAE BERENICES.

This is a superb spiral shining in the constellation Coma Berenices. It is circular in shape, and surrounding it is a cluster of small telescopic stars.

SPIRAL NEBULA IN CANES VENATICI.

A large number of the spiral nebulæ have this form.

Other spirals of great interest are:—Messier 33 Trianguli, and the large nebula in Cygnus.

A notable spiral faintly visible to the naked eye is the Great Nebula in Andromeda. As the result of spectroscopic observations made at Mount Wilson Observatory, it has been found that the inner portion of the nebula is in rotation with a motion similar to that of a solid body. One side is found to be approaching us, while the other is receding from us with a velocity of fifty miles per second. The actual distance of the nebula must be enormous. Assuming that its distance is 80,000 light years, then it follows that the extreme diameter of the nebula is about 4,000 light years.

From this uncertain estimate of the brightest of all spirals, some remote conception may be obtained of the comparative distance of the fainter ones, although the actual realization of the figures is beyond us. Within the past few years several novæ have been discovered in this nebula by means of photography. The first was found in 1885, and was of the 7th magnitude; while others, discovered in the years, 1909, 1917, 1918, 1919, were of the 16th, 17th and 18th magnitudes. If this spiral be 80,000 light years distant from our Solar System, then it follows that these faint stars must be hundreds of times larger and brighter than our Sun. Professor Harlow Shapley is of the opinion that the minimum distance of this spiral is 1,000,000 light years. At that remote distance, the diameter of this largest of spirals, is about 50,000 light

years, and those novae which have been discovered to be physically connected with the nebula, must have attained, at maximum brightness, a luminosity 1,000,000 times greater than that of our Sun. This wonderful conclusion must follow if the spiral nebulae are remote Milky Ways outside our own stellar system.

They have of late years been called "Island Universes," i.e. separate Milky Ways or universes of stars. These nebulae do not appear to have any affinity whatever to our own stellar system, but are external galactic or Milky Way systems, some of which are comparable with our own in size, while others are immensely larger. The more these fleecy-like patches in the heavens are being investigated, the stronger is the evidence that they are in reality the vastest and most impressive objects yet known to human intelligence.

MAGELLANIC CLOUDS.

In the southern hemisphere there are two nebulous-looking objects not far from the Milky Way, known as the Magellanic Clouds, so called from the well-known navigator, Magellan, who was one of the first to observe them.

Another name by which they are known is "Nubeculae," the larger one being called "Nubecula Major" and the smaller one "Nubecula Minor."

Some astronomers who have made photographs of them, are of the opinion that they are spirals resolved into stars. In the smaller cloud no fewer than 969 variables have been discovered; while in the larger one there are 808, nearly all of which belong to the Cepheid group. These clouds are enormously distant from our Solar System. Professor Shapley has estimated the distance of the smaller cloud to be 180,000 light years. Professor H. C. Wilson has made spectroscopic investigations of both clouds and finds that the twelve nebulae in the Major, are receding at the rate of 175 miles per second. These clouds might well be classed among the spirals, and be called independent systems or "Island universes."

III. PLANETARY NEBULAE.

Planetary nebulae represent the third class in the development of nebulous matter. The number at present recorded does not exceed 150. They are fairly bright bodies with a star in the centre. They are usually found in the Milky Way, and have a mean velocity of about thirty miles per second. Their apparent diameter varies from three seconds to fifteen minutes of arc. This difference in size is due largely to a difference in the distances of the bodies from us. The parallaxes of six planetary nebulae have recently been measured by Van Maanen with the 60 inch Mount Wilson reflector, and by means of these measurements, the dimensions of the planetaries have been obtained. The diameter of the largest is 10,000 astronomical units; while that of the smallest is 1,350 astronomical units.

RING NEBULA IN LYRA.

The typical nebula of this class is the Ring nebula in Lyra. This is the largest and one of the most interesting of the planetaries. In appearance it presents the form of an oval, and contains a very small star in the centre, surrounded by a mass of nebular matter. Its parallax is supposed to be 33 light years; but very probably its real distance is much greater than that.

The proper motion of this planetary nebula has been determined by the measurement of photographic plates, and it is found to be moving at the rate of five miles per second.

The colour of the star in the centre of the ring appears to be of a greenish tint—a characteristic of nebulae rather than of stars.

As to the physical character and composition of the nebula, spectroscopic investigations prove that it is gaseous. Its spectrum exhibits bright lines, proving that hydrogen and nebulium are present. The gases of which the nebula is composed, are probably in a condition of extreme rarity.

Regarding the past and future history of this Ring nebula, it is quite possible that it may have developed from a spiral nebula, and in process of time may have changed into a solid body. Professor Schaeberle held that the Ring nebula in Lyra was a closely wound spiral. Whether or not this opinion be correct, it is absolutely certain that the form of the Ring is one of transition, which may at a certain period be evolved into one more durable. Hundreds of millions of years hence, this Ring nebula may develop into a giant central sun attended by a retinue of planets, and thus become a full grown member of our own stellar universe.

PLANETARY IN DRACO.

Another well-known planetary nebula is in Draco. The spectroscope discloses to us the fact that it contains a very extensive atmosphere, consisting of the gases and vapours of hydrogen and helium. The bright lines of these gases are the most prominent in the bright-line nebulae, and in the central bodies of planetary nebulae, and also in the earliest type stars.

DUMB-BELL NEBULA.

Another planetary nebula is the "Dumb Bell" in the constellation Vulpecula. Photographs show that it is, in reality, a globular mass encircled by a dark, broad ring, which intercepts some of the light, giving the appearance of a dumb-bell. Sir William Huggins, in examining it with the spectroscope, found it contained a mass of luminous gas.

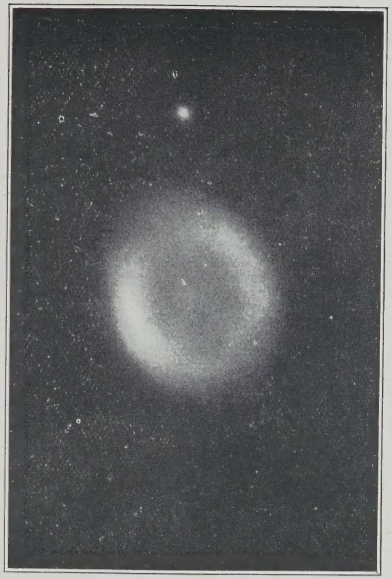
OWL PLANETARY NEBULA.

Another remarkable planetary is the "Owl" nebula. It is situated about two degrees south-east of Beta Ursae Majoris, and has an apparent diameter of three seconds of arc. Lord Rosse compared it to the face of an owl owing to its having two holes in the centre. Since then it has been called the "Owl Nebula."

PLATE XVIII.

to face page 216.

PLANETARY NEBULA.



RING NEBULA IN LYRA.

Photographed by Professor Barnard, Yerkes Observatory.

SPIRAL NEBULA M 64. Comae Berenices.

Photographed by Prof. Ritchey.

PLANETARY IN CAMELOPARDUS.

A small planetary nebula is found in the constellation Camelopardus. Its angular measurement is about fourteen seconds of arc. Its colour appears to be of a greenish-blue tint, and it has a well-defined star in the centre. The spectroscope exhibits lines of hydrogen and nebulium.

Planetary nebulae are estimated to be, on an average, one thousand light years distant, while their diameters are hundreds of times larger than our own Solar System.

Professors Campbell and Moore have found recently that these bodies are rotating around axes passing through their centres. The gases constituting the rings are rotating swiftly, just in the same way as our own Major planets are rotating rapidly on their axes.

Some think that stellar systems are being gradually evolved out of these planetary nebulae. The nebular matter appears to have been attracted into the central star that has been produced, while the remainder of the nebulosity, which revolves round the nuclear star, is left to form the constructive material for the future that may ultimately make up the complete system of planets and satellites.

Others again suppose that the planetary nebulae are products of stellar collisions.

Two theories have been brought forward with respect to the part which the nebulae represent in the production of Solar Systems.

The first is the Nebular Theory of Laplace, the great French astronomer and mathematician. He held that the nebular matter which ultimately formed our own Sun and planets, was stretched out like one of the present nebulae, and extended beyond the orbit of the outermost planet Neptune. At the commencement of its evolutionary career, it was absolutely stationary, and consequently could not revolve on its axis. But according to what Herbert Spencer at a later period

called "the instability of the homogeneous," as time went on the gravitation of the different particles of matter towards the centre of the nebula forced it to contract, thus causing it to revolve gradually at this initial stage. (Herbert Spencer was quite wrong in his "first principles." Unless there was moment of momentum to start with, the internal action of the nebula could not generate moment of momentum). The density however became greater and greater, and consequently the revolution became more rapid, until the centrifugal force became so strong that it cast off a ring. The huge mass went on contracting, until several rings were projected from the centre. These rings revolved for ages of time, but they ultimately broke through the conflict of competing forces, and the matter gradually developed into planets. After each of the planets had been formed they continued to revolve round the central mass, and owing to their swift rotation threw off rings, which, in turn, were ultimately formed into satellites.

PLANETESIMAL THEORY.

A more recent theory is that of Professors Chamberlin and Moulton of Chicago University, called the "Planetesimal." It assumes that the nebular matter out of which our Solar System has been formed, was ages ago a spiral nebula. Regarding the origin of spirals it states that if two independent suns, intensely hot, come within a distance of one hundred million miles or so of each other, great tidal waves will be raised upon each of them by their mutual attractions, causing furious outbursts of molten material from two opposite sides of each sun, and resulting in a spiral movement of the whole mass.

Concerning the formation of our Solar System, it is supposed that a massive sun approached our own Sun when it was in the first stages of its development, causing such a rupture as to form two opposite spiral branches from the matter contained in the Sun. This

matter, projected from the central mass, revolved swiftly around the parent Sun, and in doing so, threw off masses of matter, which were ultimately formed into planets and satellites.

It is probable that a number of the spirals have been formed in this way, but it is very doubtful if all spiral nebulae have been thus produced. It is not easy to understand how they could, as a whole, be formed by the close approach of two massive suns.

One difficulty in the way of accepting this theory in general, is that if the spirals are produced by two massive stars coming, say within 100,000,000 miles of each other, why are they situated in the sky where there is a scarcity of stars? Why are they not found where the stars are plentiful and where there is every opportunity for the close approximation of one star to another of similar dimensions?

It is a noticeable fact that the Novae, which are probably the result of the collisions of stars with nebulæ, are found in or near the Milky Way (and not outside this), the most densely studded region of the stars.

Professor See of Washington University, holds a theory that spiral nebulae have originated by one nebula colliding with another. Collisions of such a nature very probably happen owing to the immense size of the nebulae and their swift motions through space.

Professor Campbell is of the opinion that our stellar universe is a spiral nebula, and that our Solar System has been produced from a small portion of spiral structure, and not from a complete spiral nebula. There is every reason to believe that our Solar System was in remote ages, a nebulous mass small in size, comparatively speaking, and that our stellar universe is an "Island Universe" separated by thousands of light years from the two hundred thousand Milky Ways or universes of stars that spread their radiance through the immensities of space.

In support of this "Island-Universe" theory of the spiral nebulae, Professor Curtis, in a thoughtful and interesting article, "Modern theories of the spiral nebulae," says, "Within historical times, some twenty-seven new stars have suddenly flashed out in the heavens. Within the past two years, over a dozen novae have been found in spiral nebulae, all of them very faint, ranging from about the 14th to the 19th magnitudes at maximum. Their life history, so far as we can tell from such faint objects, appears to be identical with that of the brighter novae. Now the brighter novae of the past, that is, those which have not appeared in spirals, have almost invariably been a galactic phenomenon, located in or close to our Milky Way, and they have very evidently been a part of our own stellar system. If twenty-seven novae have appeared in our own galaxy within the past 300 years, and if about half that number are found within a few years in spiral nebulae far removed from the galactic plane, the presumption that these spirals are themselves galaxies composed of hundreds of millions of stars is a very probable one. If, moreover, we make the reasonable assumption that the new stars in our own galaxy average about the same in size, mass and absolute brightness we can form a very good estimate of the probable distance of the spiral nebulae regarded as island universes. Our galactic novae have averaged about the 5th magnitude. The new stars which have appeared in the spiral nebulae, have averaged about the 15th magnitude, but it would appear probable, that we must inevitably miss the fainter novae in such distant galaxies, and it is perhaps reasonable to assume that the average magnitude of the novae in spirals, may be about the 18th, or thirteen magnitudes fainter than those in our own galaxy. They would thus be about 160,000 times fainter than our galactic novae, and, on the assumption that both types of novae average the same in mass, absolute luminosity, etc., the novae in spirals should be 400 times further away.

We do not know the average distance of the new stars which have appeared in our own galaxy; but 100,000 light years is perhaps a reasonable estimate. This would indicate a distance of the order of 4,000,000 light years for the spiral nebulae. This is an enormous distance; but if these objects are galaxies like our own stellar system, such a distance accords well with their apparent dimensions. Our own galaxy, at a distance of 10,000,000 light years, would be about ten minutes of arc in diameter, or the size of the larger spiral nebulae."

Our whole Solar System is vast beyond all terrestrial analogies, yet it is only a small atom compared to the mighty universe of which we form a part—that universe that stretches round the stupendous circle of the heavens—our "world" in its widest and largest sense; but when we try to realise that there is universe beyond universe in the boundless depths of space, not simply great systems and constellations beyond our own, but independent circles of worlds similar to the great over-arching sky which bounds our vision here, we stagger at the very immensity of the thought. Were the whole stellar heavens, as we know them to-day, to be wiped out of existence by one sweep of an omnipotent hand, and were our vision for the moment as limitless as space itself, we should look upon no void black heavens above us, but a sky blazing with light from stars no human eyes could ever see, set thick as the gems on some monarch's crown, a crown indeed, fit emblem of the great Creator's power.

The expression is a familiar one, that "the undevout astronomer is mad." We cannot construe this in a literal sense; for many a sane scientist could not be called devout in the common meaning of the term. Yet, in a wider sense, the expression is correct. Intimacy with these great thoughts with which we have been dealing, most assuredly cannot produce contempt, and one cannot imagine any true scientist rising from a study of the great works of God without

a feeling of profound reverence, if not for the God Who is behind the laws of His wonderful creation, at least for the laws themselves in all the wide range of their activity and power.

Two conclusions, it seems to me, suggest themselves as a result of our consideration of the stellar phenomena with which we have been dealing. The first, and less important thought, though in itself a great one, is the amazing power of the human mind. It is surely a marvellous thing, when we think of it, that we, the frail, insignificant creatures of a day, have been able to comprehend, as we have done, so much of the wonders of the universe around us. To weigh the suns and the stars in the balances, to know their varied constituents and the conditions under which they exist; to gauge their velocities, inconceivable as these are in actual fact; to measure the vast distances that separate sun from sun, and system from system; to trace with unfailing accuracy the paths round which the mightiest, as well as the smallest orbs sweep on their destined way; to calculate with absolute inerrancy, the coming and going of the most erratic bodies in the heavens; to trace the life history of suns and star-drift sunk in the immensities of space, even as the biologist traces the evolution of life in our own world, or as the geologist reconstructs the history of the Earth; to build into the system of the universe, as part of its known factors, stars which the human eye has never seen even with the most gigantic telescopes; to speak, with some air of familiarity of suns and nebulae, so incredibly distant from us, that the ordinary mind reels under the weight of the mere figures—to have achieved all this, is surely no small tribute to the greatness of the human intellect, and is surely significant of man's place in the thoughts of the God Who made him, and of the destiny which awaits him in the great unknown.

And yet how significant, on the other hand, are man's limitations! Like Newton of old, he may well say he has but picked up one pebble on the beach that bounds for him the vast ocean of knowledge, stretching

before him in infinite majesty and range. After all, how little he has gathered, through all the centuries, compared to what may be forever hidden behind the veil; how small is his knowledge, when all is said, of the limitless resources of His Creator! And though he can trace the orbit of the furthest star, and predict the coming of comet and eclipse, he cannot tell what a day nor an hour may bring forth for himself or those near and dear to him. With all his knowledge and human skill, he has to confess, that day by day and hour by hour, he is dependent on the wisdom and love of his Father in heaven, Who controls, not only the path of the most distant sun, but also guides our footsteps through each unknown to-morrow.

And so we come inevitably, as we must always do, to the other conclusion, which no true astronomer can ever tire of reiterating, and to which all our thoughts of the Creation must ever lead us, not the greatness of man, but the infinite majesty of God the Creator. Sanity and devoutness are here, in the last resort, synonymous terms, but for us, this means no mere formal reverence for pitiless and unchanging laws that hold the whole world of creation, universe beyond universe, in their unrelaxing iron grip, but the sane, considered devotion of children to a Father, Who has revealed as the supreme law of life, and as the moving purpose behind all the manifestations of His power and glory—the great law of love. If, like Kant, we believe that the two great wonders of human life and experience, are the "starry heavens above, and the moral law within," we know that the greatest of these, is the moral law. And we know, beyond all doubt, that the keystone of that moral law is Love, a love manifested in every corner of the universe, and most of all in the experience of man, whose proudest achievement is, after all, that he has found God, and found Him to be perfect Love.

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